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RESEARCHES ON THE HEIGHT VARIATION OF THE ATMOSPHERIC ELECTRIC POTENTIAL GRADIENT IN THE LOWEST LAYERS OF THE AIR

INAUGURAL DISSERTATION

BY

HARALD NORINDER, LIC. PHIL. ÖSTG.

BY PERMISSION OF THE PHILOSOPHICAL FACULTY (NATURAL SCIENCE SECTION) OF THE UNIVERSITY OF UPSALA TO BE PUBLICLY DISCUSSED AT THE LECTURE HALL OF THE PHYSICAL INSTITUTION ON MAY 25th 1921, AT 10 O'CLOCK A. M., FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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RESEARCHES ON THE HEIGHT VARIATION OF THE ATMOSPHERIC ELECTRIC POTENTIAL GRADIENT IN THE LOWEST LAYERS OF THE AIR.

By *HARALD NORINDER.*

The problem of the height variation of the potential gradient of atmospheric electricity in the layers of the air close to the ground is a very interesting one. The need for researches with regard to this question has been emphasized by W. Thomson (Lord Kelvin),[1] F. Exner,[2] B. Chauveau,[3] W. F. G. Swann[4], and others. Nevertheless only one fairly careful experimental investigation into the matter has been published. It was made by A. A. Daunderer,[5] who observed the gradient at three different heights, viz. close to the ground and at a distance of 1 and 2 metres above it.

Theoretic calculations of the variation of the potential gradient in the interval 0—10 metres have, however, been made by E. v. Schweidler,[6] M. Behacker,[7] W. F. G. Swann.[8] All these authors have employed the method suggested by Sir J. J. Thomson[9] of calculating the field between the surfaces of two condensers under certain given conditions of ionisation.

A solution of this problem, in which the difference in specific velocity between positive and negative ions was taken into consideration, has been given by M. Behacker, who followed a treatment of the differential equation, which had been suggested by G. Mie.[10]

Although the experimental researches into the variation of the potential gradient

[1] W. Thomson, Papers on Electrostatics and Magnetism. — Atmospheric Electricity, London 1872

[2] F. Exner, Wiener Sitzber. *93*, 257. 1886.

[3] B. Chauveau, Annales du Bureau Météorologique 1899. Mémoires C. 7.

[4] W. F. G. Swann, Terr. Mag. *18*. 183. 1913.

[5] A. Daunderer, Dissertation. K. Technische Hochschule, München 1908.

[6] E. v. Schweidler, Wien. Sitzber. *117*, 653. 1908.

[7] M. Behacker, Wien. Sitzber. *119: 1*, 675. 1910.

[8] W. F. G. Swann, Terr. Mag. *18*, 163. 1913.

[9] J. J. Thomson, Conduction of Electricity through Gases. 64. Cambridge 1903.

[10] G. Mie, Ann. der Physik. *13*, 857. 1904.

in the lowest atmospheric layers have been very incomplete, its variation at greater heights has been investigated during several baloon ascents. The results have been considered worthy of a treatment from a theoretical point of view.[1]

Scheme and Method of Investigation.

It has generally been assumed that over a plane horizontal piece of ground of sufficient size and undisturbed by vertical objects the equipotential surfaces of atmospheric electricity under normal conditions will run parallel to the horizontal surface of the ground. The electric field accordingly lacks horizontal force components and is entirely defined by the vertical one. This is usually expressed as follows:

If the coordinates of a certain point of the air are called x, y, z, respectively, and the equation for an equipotential surface through the point in question is $V(x, y, z)$, then the components of the electric force along three coordinate axes at right angles (the z axis vertically upwards and the x and y axes in the plane of the earth's surface) are defined by the following relations:

$$X = -\frac{dV}{dx};\quad Y = -\frac{dV}{dy};\quad Z = -\frac{dV}{dz} \quad (1).$$

For a part of the field where X and Y are zero Z can with advantage be determined by observing the difference in potential between two equipotential surfaces and measuring their difference in height h, in the direction of the normal between the two surfaces. According to a suggestion by F. Exner[2] V may conveniently be measured in volts and h in metres, and hence the field force will be expressed in volts per metre.

The problem which the author set himself to solve was to determine with the greatest possible accuracy the variation with the height of the vertical component of the field force over a horizontal piece of ground. The apparatus of observation, which was to be erected on it, should be so situated that it could not considerably disturb the course of the equipotential surfaces at the points of observation, which were situated vertically above each other.

At the experiments made by A. A. Daunderer the points of observation, situated at a height above the ground of 0, 1 and 2 metres respectively, had been chosen at a comparatively great horizontal distance from each other, without his giving

[1] See H. Kahl, Dissertation. Kiel, 1915; Y. Homma, Terr. Mag. *12*, 49—72. 1907.

[2] F. Exner, Wien. Sitzber. *93*, 259. 1886.

any experimental evidence for the horizontal component of the field force always being zero all over the district of observation.

In order to measure the field force I decided to fix suitable collectors in the middle points of insulated wires stretched horizontally over the ground between vertical posts. The length of the wires compared to that of the vertical posts and of the other parts of the apparatus ought to be so great that the reference points of the collectors were situated in a field practically undisturbed by the supporting arrangements of the collectors.

The interval of observation was limited to a height of 0—9.5 metres above the ground. Up to the height of 3 metres the field force was examined by means of 3 fixed collectors at a height of 1, 2 and 3 metres respectively, while the whole of the layer 0—9.5 metres was observed by means of a movable system of collectors.

The potential differences to earth of the different collectors were observed by self-recording quadrant electrometers (electrographs of the Benndorf type), in a few exceptional cases by a Wulf string electrometer.

Preliminary investigations.

My method of observation required suitable collectors, whose qualities for the purpose had to be found out by means of laboratory experiments. The first aim of these experiments was to determine the charging qualities of different collectors and to find out which type would prove most suitable. For this purpose two fairly large wooden frames were covered with fine-meshed wire-netting and in the central parts of the frames with plane brass foil over the wire-netting.

The frames were placed horizontally on horses and insulated from them by means of paraffin blocks. The arrangements are shown in fig. 1.

In addition to this a water jet collector in the shape of a brass tube probe (visible to the left in fig. 1) was arranged in such a manner that it could easily be moved to different points between the surfaces. The jet collector was connected with a Wulf string electrometer (visible a little to the right in fig. 1).

For the preliminary observations a practically uniform field was required between the surfaces of the condenser.[1] Therefore the lower surface was connected with the earth and with the negative pole of a storage battery. The positive pole of the latter was connected with the upper surface by means of which

[1] Concerning similar arrangements see:

a) H. Ebert, W. Lutz, Beitr. zur Physik d. freien Atmosph. *2*, 5, 183. 1908.

b) K. Hoffman, Dissertation. K. Techn. Hochschule. München 1911.

c) W. Müller, Ann. d. Physik. *63*, 585. 1920.

a field was maintained between the surfaces. The potential of the upper surface was kept constant during the observations, and by moving the probe in a vertical plane between the surfaces, the force of the field at different vertical heights was observed. From these data the tollowing figure 2 has been constructed.

Fig. 2 shows that in the principal parts of the field there was a satisfactory agreement between the observed (⊙) and the calculated (geometric) potential. The latter is represented by the firm line in the figure 2.

Fig. 1. Experimental arrangement for obtaining a homogeneous electrostatic field.

An insulated wire was stretched horizontally in a vertical plane between the surfaces and in the direction of the length of the frames. The collectors that were to be tested were fixed at the middle point of this wire (indicated by the end point of the probe in fig. 1).

When I began the tests I had at my disposal only an ionium collector on sale in the market and a water jet collector of my own design. Later on, when my observations in the open air had been going on for several months, I had the opportunity of testing a gas flame collector, which I had designed for this purpose, and some polonium collectors obtained from Germany.

The ionium collectors used for the observations consisted of two circular metal plates, covered on one side with ionium. The plates were placed with their circular surfaces vertical, which made the rays run normally to the field direction. This was the position in which I intended to place them during the observations in the open air. The effective area of a collector of this type amounted to 8.3 sq. cm.

The water jet collector consisted of a metal vessel for water and compressed air to which vessel was joined a brass tube, 20 metres long and 6 mm. in diameter, the free end of which was provided with a mouthpiece that should supply a thin jet of water in case of excess of pressure in the vessel. The vessel as well as the tube could easily be insulated by means of blocks and sulphur suspension insulators.

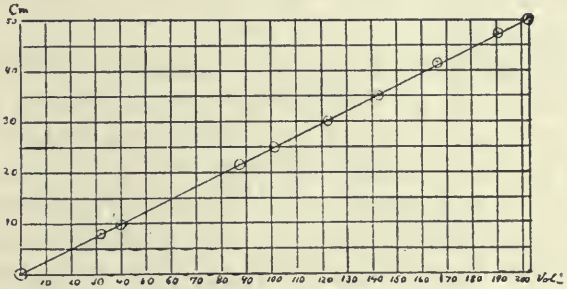

Fig. 2. Potential differences observed in the electrostatic field of fig. 1.

The gas-flame collector consisted of an insulated small gas bomb, a so-called »Aga-light» bomb,[1] connected with a 20 metres long gas-pipe. In its free end the gas-pipe was provided with a burner, which gave a very steady flame.

The polonium collectors consisted of thin sheet-copper plates, electrolytically covered on one side with a strong cover of polonium or Ra F. Each collector had a surface of 2 sq. cm. covered with polonium[2]. Like the ionium collectors these collectors were placed so that the rays should run normally to the force lines, that is with their radioactive surfaces in the vertical plane.

Two different tests were made with each of the collectors described. To begin with it was investigated what potential they assumed in the field previously described with a force of 3—4 volts per centimeter, when fixed at the middle point of the above-mentioned wire.

The observations were made by means of a Wulf electrometer No. 4238 which was also employed in certain cases to control the simultaneous difference in potential between the two surfaces of the condenser.

[1] Supplied by A.-B. Gasaccumulator, Stockholm.

[2] Some of the polonium collectors supplied later on had a larger surface covered with polonium.

The tests showed that within about one minute the ionium, polonium and water jet collectors were charged from the potential o to a potential that did not considerably differ from the calculated geometric potential of the field at the middle point of the supporting wire. This was not, however, the case with the gas-flame collector. It is true that within 40—60 seconds it would sometimes assume the geometric potential prevailing for the discharge opening of the gas-burner, but this happened only occasionally. In most cases its final potential differed with 10—20 % from the geometric one. The explanation of this fact was to be found in the considerable deformation of the field that was caused by the great number of heavy ions escaping from the gas flame. No improvement was to be gained through experiments with a shielding cylinder of fine-meshed wire-netting. The divergences from the geometric potential were sometimes positive, sometimes negative, and it was evident that flame collectors were not suitable for my observations.

According to the method of observation as indicated above the collectors were during the observations in the open air to be attached to a comparatively long wire. To about 20—30 % of its length this wire should be situated in a field whose potential did not considerably differ from that of the point of observation. The rest of the wire should, on the other hand, have to pass through layers with sometimes very different potential. By this means great losses could be caused to the system and it was very important to choose collectors strong enough to make up for those losses by their own charging capacity.

This was tested in the following manner. To the collector in operation, suspended on the above-mentioned insulated wire between the surfaces of the condenser, was joined an insulated iron wire, 50 metres long and 1 mm. in diameter, running outside the condenser field, that is to say in a layer where there was no electric field.

When this connection was made the rate of charging of the ionium collectors proved to be too weak. The potential assumed by the system, which was not reached until after 5—6 minutes, was that of a point 5—7 cm. lower than the supporting wire in the field. The reason for this was the comparatively small activity of the ionium preparation through which the losses in electricity of the system outside the point of observation could become so great that its final potential was considerably less than that of the supporting wire in the field. This test showed that ionium collectors of the surface capacity I had used were not suitable for my observations. An experiment in which the 50 metres long polished iron wire was replaced by a rubber-covered copper wire did not improve the result.

A similar test with the above-mentioned water jet collector, on the other hand, did not show any considerable difference between the potential assumed by the

collector system within one minute and the one prevailing at the middle point of the supporting wire. This fact was the more remarkable because with the water jet collector had been connected, besides the 50 metres wire, an extra capacity in the shape of a big insulated water-tank of galvanized iron.

On account of the war I could not get polonium at the beginning of my investigations in the summer of 1918. Because of the experiences gained through the preliminary experiments I accordingly decided preferably to use water jet collectors for my observations of the variation with the height of the potential gradient. They had proved suitable in every respect.

It was not until in October 1918 that I could obtain from Germany 6 sheet-copper plates, covered on one side with freshly produced polonium, each on an area of 1 sq. cm. A collector was made by combination of two such plates to an effective surface of 2 sq. cm. Concerning the fastening of the sheet-copper plates with polonium to the collector wires, see further page 30 and fig. 14. At the end of October I got an opportunity of testing the new collectors by the same method as previously the ionium collectors. The connected wire outside the field had a length of 31 metres.

Tab. 1 shows the data obtained at the tests of the charging qualities of the three polonium collectors. The distance between the condenser plates during the experiment was 53.0 cm. and the height of the collector wire above the lower plate was 30.1 cm. The positive storage potential of the condenser that was not earthed amounted to 211 volts.

Tab. 1.

Collector No.	Observed potential of the collector system, volts.	Calculated potential at the centre line of the wire, volts.
1	117.8	119.3
2	117.9	119.3
3	117.7	119.3

Accordingly it was found that within a minute after the earth connection was broken the collectors assumed a potential, situated 0.4 cm. below the geometric potential of the supporting wire in the condenser field. By this test the usefulness of the polonium collectors for my observations was established, especially as the conditions in the open air were more favourable than in the laboratory with regard to the length of the wire not exposed in the field. All the same I did not consider it advisable to rely entirely on the laboratory experiments I had made with regard to the charging capacity of the polonium collectors. Therefore the tests were repeated in the open air at the place of observation.

Details will be given in what follows. Such a verification in the open air was the more necessary as by this means a check was obtained of the decrease in the activity of the polonium preparation which is bound gradually to take place.

The importance of the tests of the collectors which were made, is obvious. Let me give an example. In May 1919 I received from the same firm that had supplied the earlier set of polonium plates another set of the same kind, claimed to have the same properties as the first sending. When tested those plates showed too small activity and had to be returned for further electrolytical covering with polonium.

Daunderer's work, otherwise very praiseworthy, has one serious fault. No tests of the collectors were undertaken, neither with regard to the deformation caused by the flame collectors nor with regard to their charging effect. Daunderer himself says that the conducting wires between the electrometer and the collectors had to be kept tightly stretched during his observations. If for some reason or other they became sleak the observed deflexions on the electrometer were diminished. This may possibly indicate a certain weakness in the charging effect of the collectors, as an efficient collector ought to be practically independent of the position of its conducting wires, if they are as short as in Daunderer's experiments.

My preliminary investigations included also the finding out of suitable insulators and other devices. Especially the question of the insulators offered certain difficulties, as because of the war and the blockade maintained by the Allied Western powers the only insulating material suitable for the investigations that could be obtained was sulphur. In some of the insulators it had to be subjected to great pulling strain. By putting the sulphur in conical iron caps I succeeded in making them stand comparatively heavy strains. See further the special description of the apparatus.

The Place of Observation.

As a locality for observing the atmospheric electric field was chosen a level piece of ground, situated about 100 metres to the south-west of the Instrument Building of the Meteorological Institution of the University of Upsala. Its situation was such that the equipotential surfaces should be practically horizontal within a small area, if the disturbances caused by the erection of the exterior apparatus that was necessary for the observations were not taken into consideration. In order to eliminate the irregularities of the ground, galvanized iron wire-nettings, stretched over a wooden frame, were placed on the surface of the ground. The collectors used for the observations were fixed in vertical planes, situated over the middle parts of the wire-nettings. As the nettings were in

direct contact with the ground a zero potential surface was accordingly obtained, which could be kept practically constant during the whole time of observation.

The locality of observation had a fairly open situation without being ideal.

In fig. 3 is shown a plan of the place of observation in which the posts and the instrument hut are indicated by the letter *A*. The rectangular area to the right of *A* in fig. 3, surrounded by roads, are the premises of the Observatory

Fig. 3. Map showing the surroundings of the place of observation.

with the Instrument Building of the Meteorological Institution situated straight to the right of *A* in fig. 3. At about the same distance below *A* in the figure the Epidemic Hospital of Upsala is situated.

Outdoor Arrangements.

On the observation ground were erected a wooden hut for the instruments and four vertical posts, 3.3 metres and 9.5 metres[1] in height respectively and at

[1] The actual height of the longer posts was 9 metres above the ground, but considering their supporting iron bars their height from an electrostatic point of view became 9,5 metres.

a horizontal distance between the shorter posts of 18 metres, between the longer ones of 43 metres.

The general appearance of the observation ground with the exterior apparatus is shown in fig. 4.

The Stationary Collector System.

Between the two shorter posts in fig. 4 the horizontal insulated steel-wires T_1, T_2 and T_3 were fixed at a height above the ground of 1, 2 and 3 metres respec-

Fig. 4. Instrument hut with low posts and water jet collectors.

tively. The outdoor insulation of the wires was maintained by means of electrostatic insulators, which I had specially designed.

The exterior appearance may be seen in fig. 4 (for instance I_3 and I_6).

As insulating material was used sulphur as mentioned above. As it would be subjected to a fairly great mechanic strain it was cast in a strong iron cap, narrowed towards one end and threaded on the inside. A sketch of the exterior insulator is given in fig. 5.

On the whole very high demands were put on the insulating capacity in this investigation. The insulators just described, for instance, had to work well also in moist air. Therefore they were shielded from water by thick caps of galvanized sheet-iron. For the drying of the sulphur surfaces of the insulators situated in the air, the caps of the insulators had been provided with special arrangements for drying, viz. glass bottles containing calcium chloride and bowls with calcium carbide, see fig. 5. The supporting insulators inside the hut were constructed according to the same principles as the exterior insulators. (See lower diagram in fig. 5.) The insulators used for the investigations showed, according to often repeated tests, a very good capacity of insulation during the time of observation (see page 32).

In order to avoid a sagging of the horizontal wires T_1, T_2 and T_3 changing with the temperature they were tightened by means of special straining weight arrangements, whose appearance and construction are shown by fig. 4 and 5. The pulley visible in fig. 5 was provided with ball bearings, which made the arrangement work so excellently that no variation of the height of the wires with the temperature of the air could be noticed, not even for differences of temperature amounting to 40 degrees centigrade.

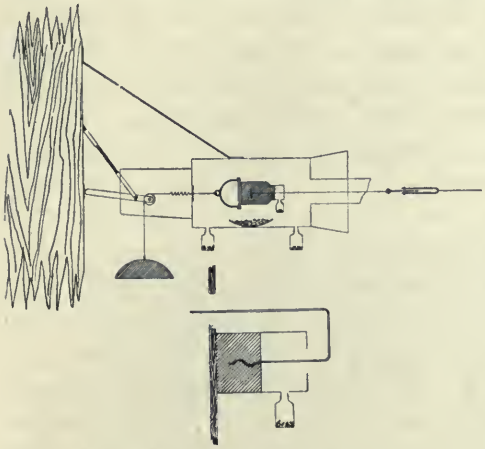

Fig. 5. Sketch of insulating supports and outdoor insulators.

It has already been mentioned that the method of observation employed by the author[1] required that collectors should be fixed at the middle points of the insulated horizontal wires which had been stretched at the heights of 1, 2 and 3 metres respectively.

According to the results of the preliminary tests only water jet collectors or polonium collectors of high activity could be used for my investigations. Polonium could not be procured until in the autumn of 1918 and since the observations had to be commenced in the summer of that year, I decided to construct a special arrangement for water jet collectors. The main characteristics of this arrangement are the following. Along the above-mentioned horizontal wires were suspended brass-pipes with an outward diameter of 6 mm. By this arrangement water under pressure could be led to the water jet collectors fixed at the middle points of the wires (P_1, P_2 and P_3 in fig. 4). Under certain conditions the equipotential surfaces would remain practically undisturbed at those points.

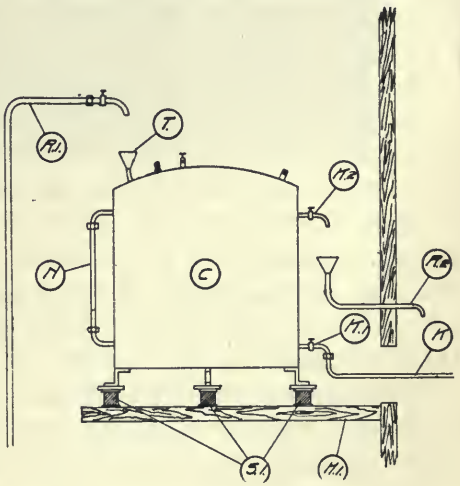

Fig. 6. One of the three tanks used for the water jet collectors.

[1] A modified form of the method was often used during the last 30 years for the determination of the factor for reducing potential differences to volts per metre. The method used here is described by G. C. Simpson, Phys. Zeitschr., *14*, 41—45, 1913, and was used by C. T. R. Wilson; see C. Chree, Phil. Trans. Roy. Soc., London, *215*, A. p. 135, 1915.

When the systems were in operation the diameters of the water jets were about 1 mm. The horizontal wires were in direct connection with the mouthpieces of the pipes. The wire systems accordingly assumed the potential prevailing at the point of the air where the jets spread into small drops. The whole system was adjusted in such a manner that the spreading-point of each jet would be at the same height above the ground as the supporting wire.

The water pressure required for the jets was obtained from three practically identical water tanks, which were placed in the instrument hut. The details of the arrangement of one of those tanks are shown in fig. 6. The tank C, insulated by the sulphur blocks S_1, was placed on the shelf H_1.

The pipe K conducted the water from C to the corresponding mouth piece. The system was put into operation in the following manner. First a certain quantity of water was poured into the tank C and the height of the water was observed by means of the gauge glass N. Then water was turned on from a common water cistern placed on the roof through the pipe R_1, which was provided with a stop-cock. This water fell down by drops into C through the funnel T. The size of the drops was regulated so that the same quantity of water should drop in through T per unit of time as poured out through the corresponding mouthpiece. A great advantage was gained by this arrangement. The difference of level between the open surface of the water in the tank and the mouth-piece could be kept constant, and thus it was avoided that the position of the point in the air, whose potential should be observed, varied with the height above the ground.

The three water jet collectors could all be working steadily for several days without any attention. Sometimes, however, a mouthpiece would get choked up, which at once appeared in the registrations as a fall in potential. In order to avoid overflow on such occasions, the tank was provided with the discharge pipe K_2, corresponding to the funnel R_2. If the water was stopped in a mouthpiece, the fixed quantity of water that dropped in through R_1 would drop out through R_2, and the tank C would still remain insulated.

One disadvantage of the water jet collectors was their unreliability in operation and another the impossibility of using them in winter-time. In October 1918 I therefore replaced them by polonium collectors, which were attached to the middle points of the collector wires.

The Movable Collector System.

For the observation of the potential difference up to 9.5 metres height was used a movable collector system, placed on the above-mentioned 9 metres posts, which

were located in a plane parallel to the lower posts and at a horizontal distance from them of 1.3 metre. The high posts together with the instrument hut etc. are shown in fig. 7.

On the high posts were fixed vertical iron bars, which served as guides for the specially designed carriages that supported the collector wires with their insulators in uniformly placed holes. The carriages ran very smoothly on pulleys provided with ball bearings, and the vertical distance from one collector to the other could easily be altered by one single manipulation. By means of a le-

Fig. 7. Instrument hut with high posts for movable collectors.

velling instrument a zero-point was marked out on the guides on level with the fixed frame midway between the posts, and from this point a scale line was made on the guides for each decimetre up to 9 metres. A collector carriage of this type together with part of a guide and two insulator caps are shown in fig. 8.

If the carriages were placed at the same scale lines on the guides, the wires would be practically parallel and horizontal. In order to attach the carriages firmly to the guides and to keep the sagging of the wires constant and equal for both the wires, extra strong spiral-springs were made and fixed between the carriages and the insulators of one of the guides. The pull on the wires was measured by means of a spring-scale and the tension and length of the wire were adjusted so as to make the pull 30 kilograms on each wire.

The unavoidable but inconsiderable sagging at the middle point of the wire was by this means fixed to 10 centimetres. The sagging was often checked and

proved to be practically constant. When the carriages were moved vertically with their collector wires in a horizontal direction the distance between the two wires did not vary to any noticeable extent. The reasons for this were of course to be found partly in a careful adjustment of the guides in the vertical

Fig. 8. Photograph of collector-wire carriage, guides, and protecting caps, on the 9 metres posts.

plane, which was obtained by means of special tightening stays on the high posts, and partly in the equal tension of the wires. The moving of the carriages to different heights was performed from the ground by means of small blocks and falls with steel-wire cables. The appearance of the arrangements is shown by fig. 7 and 8.

Electrometers.

The potential difference between the earth and the different collector systems was during these investigations recorded with quadrant electrometers of Benndorf's construction (electrographs). Each instrument was placed in a case of its own, which in winter was kept warm by means of electric lamps.

The electromagnetic registration had been arranged in such a manner that the three electrographs were connected with their electromagnets in parallel. A clockwork, common for the three electrographs, closed an electric current passing through the registration electromagnets during about three seconds each minute, and the same clockwork closed for every full hour a circuit passing through another system of coupled electromagnets for hour marking. The recording thus took place at the same moment on all the three electrographs.

By means of small jars containing calcium chloride the insulators inside the coverings of the electrographs were kept in good condition. Glycerine was always used as damping liquid and proved to be better than sulphuric acid. The concentration of the latter could more easily vary in the different electrographs, which might cause a difference between the damping in them, and in case of rapid variations of potential, errors might possibly creep into the registrations. The concentration of the glycerine could easily be kept constant as the drying-jars absorbed all moisture. The slight errors at the zero-positions, which sometimes will occur when damping with sulphuric acid, did not appear when using glycerine, which was another advantage of glycerine as a damping liquid.

For the charging of the three recording electrographs I used one single quadrant battery with zinc and copper electrodes in a solution of magnesium sulphate, $Mg\,SO_4$. The quadrants of the three electrographs were thus all charged to the same voltage. An eventual change in quadrant voltage produced a corresponding change in the sensibility of all the three electrographs. In winter-time the battery and the electrographs were warmed by means of electric lamps.

As standards for the voltage measurements were used a new precision voltmeter of the Siemens-Halske type, number 981628 with a multiplier number 995300, duly tested after its arrival from Germany, and a Wulf string electrometer, number 4238, which also had been carefully calibrated at the Testing Laboratories of the Royal Technical Institute at Stockholm, Electrotechnical Department, by means of a precision voltmeter for direct current, number 380214, of Siemens-Halske's type belonging to that institution. The calibration curve of the Wulf electrometer varied a little with the temperature, and in order to avoid errors at low temperature it was in the cold season put in a wooden box with double walls, and the space between was filled with crumpled paper. When warmed

with an electric lamp of appropriate size and placing, the interiour of this box showed very constant temperature.

Calibration of the Electrographs.

After the installation the different quadrant electrographs were very carefully adjusted for the following connections. The quadrants were connected to the positive and negative pole respectively of the quadrant battery, the necter of which, as well as the coverings of the electrographs, were earthed by means of a special earth-connected wire. During the calibrations the want for small storage batteries of Klingelfuss' type was strongly felt. Instead of those I had to make about 900 Mg SO_4-cells, combined into batteries permitting the choice of suitable connection combinations.

The ordinary calibrations were made as follows. A certain number of Mg SO_4-cells were connected simultaneously to all the three electrographs, which were made to record during the same period of time, generally five minutes. The electrographs were at those calibrations tested not only for different needle voltages within the limits of the normal deflections of the electrograph in question but also for different quadrant voltages. The quadrant voltage usually employed was 50 volts, sometimes 30 volts. From the deflexions the calibration constant for each electrograph was easily figured in the usual way. The voltage of the quadrant battery as well as that of the Mg SO_4-cells was at each calibration observed by means of the Wulf string electrometer, which in its turn was checked with the above-mentioned voltmeter.

In table 2, given below, are for instance shown the observed calibration constants for $\pm$ 50 volts on the quadrant together with the dates of the different observations. In the beginning of the investigations the needle systems often had to be dismounted for different reasons, which caused a comparatively short validity for the different constants. In table 2 these constants are expressed in volts per millimetre of deflection. The quadrant electrographs are numbered 1, 2, and 3, the respective figure indicating the height in metre above the ground of the fixed co'lectors to which the electrograph in question was connected. The times during which the respective calibration constants were valid are indicated by brackets in tab. 2.

The calibration constants observed during a certain period, e. g. 28.8 11 a. m.[1] —16.2 1 p. m. were brought together to an average, which was used for the deduction into volts of the records of the period in question.

When Mg SO_4-cells were used as quadrant battery, small variations of this voltage could not be avoided. At the beginning of the observations (Aug. 1918) the voltage of the quadrant battery was therefore observed every day during a week. The variation was less than 1 %, and so I did not consider it necessary

[1] In the following the dates are for brevity written e. g. August 28th = 28.8, and p. m. and a. m. are shortened to p. respectively a.

Tab. 2.

Date.	Volts/mm. No. 1	Volts/mm. No. 2	Volts/mm. No. 3
1918 10.8	7.0 (1.8—12.8 5 p.)	7.2 (1.8—18.8 5 p.)	10.3 (1.8—18.8 11 a.)
18.8	7.5	7.5 (18.8 6 p.—19.8 8 a.)	11.5
19.8	7.4 (12.8 6 p.—28.8 10 a.)	7.2 (19.8 9 a.—	11.4 (18.8 11.30 a.—
23.8	7.4	7.1 28.8 10 a.)	11.3 28.8 10 a.)
28.8	7.5	7.8	11.4
14.9	7.6	7.7	11.4
25.9	7.5	7.8	11.3
7.10	7.6 (28.8 11 a.—16.2 1 p.)	7.8 (28.8 11 a.— 16.2 1 p.)	— (28.8 11 a.— 16.2 1 p.)
18.11	7.6	7.7	11.4
1919 18.1	7.4	7.8	11.4
13.2	7.6	7.9	11.4
16.2	7.4	7.8	10.9
8.5	7.5 (16.2 2 p.— 20.5 2 p.)	7.8 (16.2 2 p.— 20.5 2 p.)	11 0 (16.2 2 p.— 20.5 2 p.)
20.5	7.4	7.7	10.9
20.5	7.5 (20.5 3 p.—	7.7 (20.5 3 p.—	10.9 (20.5 3 p.—
27.7	7.5 31.7 12 p.)	7.7 31.7 12 p.)	11.0 31.7 12 p.)

to check the voltage of the battery too often. During the observations with the fixed system of collectors from 1.8 1918 to 31.7 1919 the voltage of the quadrant battery was checked on 43 different occasions. Except for a few cases of defects in the insulation of the quadrant battery, the variation between two observations amounted sometimes to 3 %, but as a rule it was about 1 %. For days between two observations the voltage of the quadrant battery was obtained by means of linear interpolation. The figures thus obtained were used to correct the calibration constants of the respective quadrant electrometers.

For a small interval of variation full proportionality had to be presumed between the quadrant voltage and the corresponding calibration constant. I considered it, however, my duty to prove this presumption by experiments, and so in July 1919 the calibration constants for a quadrant voltage varying with 10 % on both sides of arithmetical mean for the quadrant battery were determined. This was done by means of a successive addition of new cells. If the calibration constants thus obtained were plotted out in a co-ordinate system, as functions of the quadrant voltage, straight lines were obtained, which may be

considered to have proved experimentally the presumption of a full proportionality between the quadrant voltage and the calibration constant.

With regard to the calibration of the quadrant electrometers it was necessary to find out if they were adjusted in such a manner that proportionality prevailed between the deflection and the needle voltage within the limits of registration. Several tests of this kind were made without any divergence between them. The results of one of those determinations is e. g. shown graphically in fig. 9 below, in which the observed values are represented by the sign ∘. The values are those of the voltage of Mg SO_4-batteries connected up in series, and observed with the Wulf string electrometer. The figure shows that there was such a proportionality.

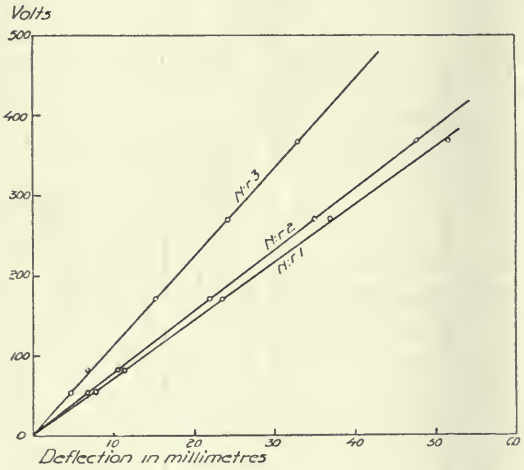

Fig. 9. Diagram showing calibration constants of electrographs as a function of deflection.

At the observations of the potential gradient with the movable system of collectors, from Aug. 21st 1919 to Aug. 13th 1920 the quadrant voltage of the battery was specially checked for each observation. The calibration constants of the electrographs were at those observations sometimes determined by the following convenient method, especially in the winter. All the three instruments together with the precision voltmeter and a suitable multiplier were connected to the city lighting-system. The voltmeter was read directly for each registration and the calibration constants of the different quadrant electrometers were deduced from their simultaneous registrations. By this method determinations were obtained for different deflections up to 220 volts needle voltage. For higher voltages the three electrographs that were connected to one another were charged by means of a glass-pipe, which was rubbed with silk, to a series of different voltages up to the limit of deflection. The electrographs were then made to record simultaneously, whereby a test was also obtained as to the insulating qualities of the needle-system of the electrographs and of the supporting insulators. The voltages of the connected needles of the electrographs that corresponded to higher deflections than 220 volts were obtained by calculation from the calibration constant of one of the three electrographs. This constant was as mentioned above determined for different deflections up to 220 volts needle voltage.

Inaccuracies of the Observations caused by Defects of the Apparatus and Instruments.

Defects of the Calibration Instrument.

The Wulf string electrometer sometimes used as voltage standard for the observations had as already mentioned been calibrated at the Testing Laboratory of the Royal Technical Institute at Stockholm. As a standard of calibration was used a precision voltmeter, No. 380284 of Siemens-Halske's latest construction. The calibration showed a maximum error of 0.2 per cent. Investigations by the author[1] had shown that the Wulf electrometer had a certain coefficient of temperature and therefore care was taken to keep the temperature of the electrometer when in operation not very different from that prevailing at the calibration at Stockholm.

As previously mentioned, the Wulf string electrometer was calibrated for control at Upsala by means of a precision voltmeter of Siemens-Halske's type No. 981628,[2] giving corrections that for some scale-divisions amounted to 0.1 volt and for the others still less.

The defects of the calibration instruments used for the observations were thus negligible for my investigations, their accuracy being far greater than was required.

Errors in the Calculation of the Potentials from the Records.

In another context (pag. 36) I have described the methods of reading the registration-curves. They showed that the ordinate values might be considered to have been read with an accuracy of generally about $(\leqq) \pm 0.1$ mm., exceptionally $(\leqq) \pm 0.2$ mm. In wiew of this fact and of the accuracy of the respective calibration constants the probable error in the individual hourly values (see page 36) of the potential differences of the respective electrographs may be taken to be of the magnitude of up to 1.0 volt on the uppermost and exceptionally up to 2.0 volts. The accuracy obtained at this potential registration is in fact the one generally occuring at registrations of atmospheric electric potential with Benndorf's quadrant electrometers. These errors in individual observations are of course considerably decreased in all mean values.

Inaccuracies caused by Disturbances from Posts and Instrument Hut.

According to the general method the investigations were to be made in an atmospheric field where the equipotential surfaces were practically undisturbed by exterior arrangements. This could most easily be gained by making the distances from the respective collectors to the posts and the instrument hut

[1] Harald Norinder, Kungl. Sv. Vetenskapsakademiens Handlingar *58*. No. 4 p. 9. Stockholm 1917.

[2] This instrument was as mentioned above calibrated at the Testing Laboratories of the Royal Technical Institute at Stockholm.

sufficiently great. My preliminary investigations had shown the defects of the ionium collectors with regard to their rate of charging. At the time when the apparatus was erected I had, however, to reckon with the use of radioactive collectors of some kind for the observations in winter. As those collectors could not be procured until at the end of October and the investigations were started at the beginning of August 1918 I decided to arrange the apparatus in such a manner that the length of the wires between the posts became the shortest possible. If I had possessed my later experience with regard to the charging qualities of polonium collectors when I designed my apparatus, I should not have hesitated to make the distances between the posts a little longer.

At the calculation of the required distance between the posts I started from

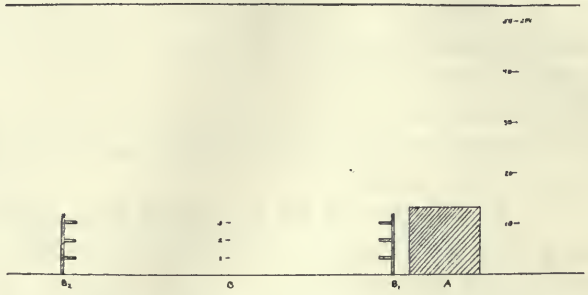

Fig. 10. Model of instrument hut and low posts used for estimating their electrostatic disturbance.

some approximate estimates of disturbances in equipotential surfaces, which have been made by H. Benndorf[1] for posts on level ground. According to Benndorf a vertical post, 1 metre high and at a horizontal distance of nearly three times its height, caused an error in the potential of less than 1 % at a height above the ground from 0 to 1 metre and this error grew less for greater height. Both with regard to the high posts and the low ones, the disturbances in the equipotential surfaces of the field where the collectors were placed would accordingly be so small that they could be left out of consideration.

Far more difficult was the estimation of the combined disturbances of the instrument hut and the posts and stays. This had to be ascertained by experiments. A geometrically corresponding model of the instrument hut together with posts and stays was introduced in the laboratory field described on page 4, in which the distance between the condenser plates had been made sufficiently great in proportion to the model. The arrangement with dimensions is shown in fig. 10.

[1] H. Benndorf, Wien. Sitzber. *115*. 445. 1906.

Observations of the potential were made with the water jet collector in the centre plane between the posts in the model [indicated in the figure 10 by the numbers 1), 2), and 3)], first when the model was placed in the field and then after it had been taken away.

Through the introduction of the model the equipotential surfaces were raised, for the point 1): 1.9 %, for 2): 2.0 % and for 3): 1.8 %. (The field force at the observations was 6 volts per cm.) Observations in the open air with the stationary collector system at 1, 2, and 3 metres height above the ground would accordingly result in values that were 2 % too low.[1] The gradient values for the stationary system given below should therefore have been raised 2 %. I have, however, considered it to be more convenient to give the *observed* values, which in order to avoid mistakes will be pointed out when necessary in what follows. Precise values of the gradient as observed with the stationary system can be obtained simply by multiplying the values given below with 1.02. The fact that the disturbance of the values of the stationary system in the observed points amounts to 2 % is principally due to the combined disturbing effect of the instrument hut and the post close by. In the points of observation of the movable collector system, on the other hand, the disturbances will probably be a little smaller considering the great distance, 43 metres, between its 9.5 metres-posts, and the position of the observation points in a vertical plane at a distance of 1.3 metre from those of the stationary system.

Another estimate of the inaccuracy caused by the instrument hut and the posts was obtained in the following manner. The collector that was placed at the height of 1 metre above the ground, was removed 60 cm. to each side of its normal position and its potential under undisturbed conditions was observed. If we denote its position 60 cm. nearer to the hut with No. 2), the normal one with No. 1) and the one 60 cm. nearer to the farther of the low posts with No. 3), the following average potential was obtained during 10 minutes on days with even potential for observations in the different positions on two different days in October 1919. The second day was characterized by very undisturbed conditions, while on the first day precipitation followed half an hour after the conclusion of the observations.

Position	1)	2)	3)
First day	88.8	86.8	86.5
Second day	60.7	61.4	59.7

[1] These values concerning the raising of the equipotential surfaces agree entirely with the observations of K. Hoffman. Dissertation K. Technischen Hochschule. München 1911, p. 31. He found that at a distance of three times the side length of a cube counted from its centre the rising of the equipotential surfaces caused an error in the potential gradient of two per cent.

As will be seen the differences are comparatively small. The differences of the first day between 1), 2) and 3) are probably caused by variable electric volume densities preceding the precipitation.

Yet another test for checking the disturbance caused by the hut and the short and long posts was made in the plane of the movable system of collectors. The potential difference was recorded during five minutes for the height 1 metre on the fixed system of collectors, dv/100, and simultaneously for the movable system at the heights 1.25, 2.25, 3.25, and 4.25 metres above the ground in the vertical plane of the high posts at a horizontal distance of about 18 cm. parallel to one wall of the instrument hut. The observations for the movable system, as for instance that for 1.25 metre height, were made as follows. The lower collector was placed exactly 100 cm., the higher one 143 cm. above the ground and the observed difference of potential between them was converted into volts per 50 cm., dv/50 cm. in tab. 3.

As vertical lines of observation were chosen first the vertical centre line between the high posts, i. e. the line in which the ordinary observations of the potential gradient from 0 to 9 metres with the movable system were made and then two lines, 3a (in the tab. 3), situated near to the hut at a distance from the centre line of 3 metres, and line 3b, situated at the distance 3 metres on the other side of the centre line counted from the hut. For each pair of observation points the potentials were observed simultaneously on the lower and upper collectors of the movable system and on the collector at 1 metre's height in the fixed system.

A comparison of the values of dv/50 in the different planes of observation in tab. 3 No. 1) and 2); No. 3) and 4); No. 5) and 6); No. 7) and 8), shows that there are some differences. But if the values of dv/50 are corrected for the simultaneous variation of the potential gradient dv/100 during the time of observation in the fixed collector system (corrected values tab. 3), there is practically no difference worth mentioning in the values for dv/50 for the planes 3a to 3b compared to the plane 0.

It could accordingly be considered as experimentally proved that the exterior apparatus of observation in the shape of posts and instrument hut did not disturb the course of the equipotential surfaces more than was consistent with the accuracy of observation otherwise obtained.

Inaccuracies caused by Defects in the Charging Effect or in the Insulation of the Collector Systems.

In another context pag. 5 I have given an account of the preliminary investigations of the charging capacity of different collectors. Those observations were made

Tab. 3.

Height in metres.	Upper and lower collectors. Volts.	dv/50 in cm.	Corrected values.	dv/100 in cm.	Height in metres.	Upper and lower collectors. Volts.	dv/50 in cm.	Corrected values.	dv/100 in cm.
9 Sept. 1920 9a.—11a. Observation line 3a. No. 1.					Noon—1 p. Observation line 0 No. 2.				
1.25	68 44	28	25	46	1.25	67 43	28	27	43
2.25	120 93	31	29	45	2.25	126 99	31	28	46
3.25	160 138	26	32	32	3.25	194 166	32	26	51
4.25	200 175	29	30	40	4.25	220 196	28	26	45
9 Sept. 1920 2 p.—3 p. Observation line 0 No. 3.					3 p.—4 p. Observation line 3b No. 4.				
1.25	95 63	37	37	65	1.25	84 59	29	30	64
2.25	144 119	29	32	59	2.25	168 130	44	41	68
3.25	198 171	31	34	59	3.25	253 216	43	38	73
4.25	255 227	34	37	60	4.25	313 275	44	37	75
10 Sept. 1920 10a.—11 a. Observation line 0 No. 5.					Noon—1 p. Observation line 3a No. 6.				
1.25	46 32	16	21	32	1.25	69 52	20	19	49
2.25	93 77	19	24	36	2.25	160 128	37	26	63
3.25	165 145	23	27	39	3.25	227 197	35	27	59
4 25	248 220	32	32	48	4.25	264 238	30	26	54
20 Sept. 1920 1 p.—2 p. Observation line 0 No. 7.					3 p.—4 p. Observation line 3b No. 8.				
1.25	82 56	30	29	54	1.25	85 58	31	29	57
2.25	157 127	35	32	58	2.25	124 100	28	35	40
3.25	172 148	28	32	46	3.25	202 176	30	28	57
4.25	258 230	32	32	53	4.25	252 224	32	31	55

indoors, but the collectors were to be used in the open air. I therefore decided to repeat the tests at the place of observation. The condenser system already described was installed on both sides of one of the 43 metres collector wires. A photograph of the arrangement is given in fig. 11.

During the actual observations the beams supporting the condenser plates were, unlike the arrangement in the fig. 11, placed at a distance of 2.5 metres and at

Fig. 11. Electrostatic field plates used for testing the polonium collectors when in operation.

the very edge of the condenser. The distance between the condenser plates was also considerably less than the one shown in the figure. As a rule it was about 50 cm. The lower condenser plate was during the observations covered with a sheet iron plate 90 × 30 cm., not visible in fig. 11. A scheme of the connections is given in fig. 12.

The high posts are represented by the figures 1 and 2 in fig. 12 and at the point 6 the wire stretched between them carries the collector whose charging capacity is to be tested. The surfaces of the condenser are indicated by 3

and 4. The surface 4 is earthed and on 3 is placed a positive potential of about 220 volts. The string electrometer, by means of which the potential difference of the collector system to earth is observed, is indicated by 9, while the potential of the surface 3 during the experiment is observed by means of the resistance 8 and the precision voltmeter 7 or eventually by means of a quadrant or a string electrometer.

On Febr. 9th 1919 the three polonium collectors that since Oct. 1918 were in use, each on one of the three wires of the fixed collector system, were tested.

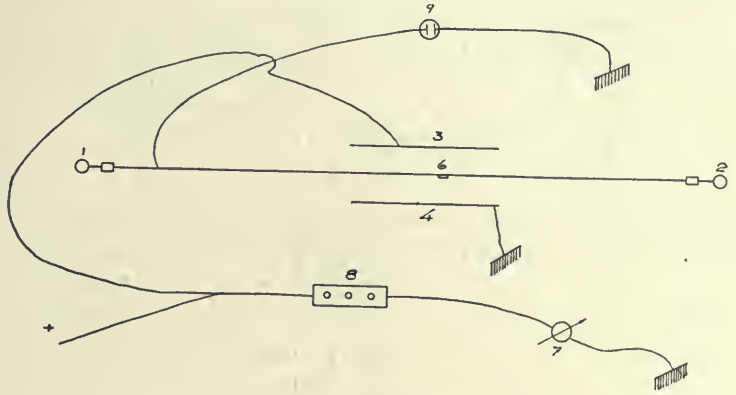

Fig. 12. Connections for the fig. 11 test.

The distance between 3 and 4 (in fig. 12) was 52.2 cm., that between 6 and 4, 19.5 cm., and the average potential of 3 during the experiments was + 221 volts. The results of the observations are given in tab. 4.

Tab. 4.

Collector No.	Observed difference of potential.	Calculated difference of potential.
1	79.5	82.5
2	79.6	82.5
3	79.5	82.5

The wire system with one of the collectors attached to it thus assumed a potential corresponding to the calculated potential of a collector wire situated 0.7 cm. lower in the condenser field than at the observation. Considering that at the registration with the electrographs the collectors were attached to the

considerably shorter wires between the lower posts, and that the collector systems thus had less capacity, the results of the observations were considered to be satisfactory, especially as in the experiments the whole of the collector system was charged to a potential highly different from that of the surroundings, while this was not to the same extent the case during the actual observations.

As the thin polonium-covered copper-plates, which were obtained in May 1919, showed too weak radiating power, I decided to try to use water jet collectors for the movable collector system that would permit jets even to the height of 9.5 metres. Only some preliminary observations of the potential gra-

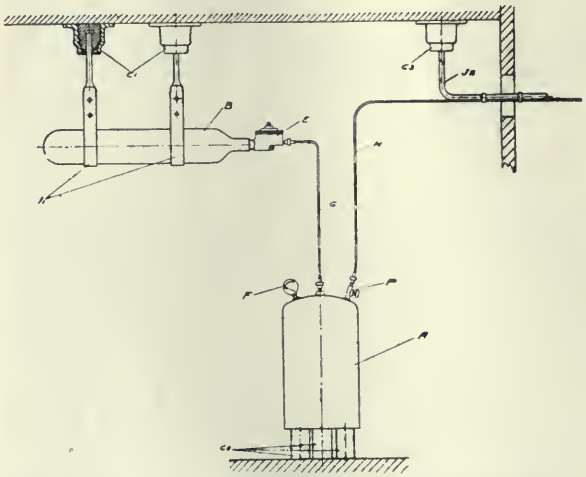

Fig. 13. Sketch of a water jet collector arrangement operated by compressed carbonic acid.

dient in the open air were made by means of the arrangement, but as it may be of use for observations of atmospheric electricity, especially in southern countries, I think I had better describe the method in this context. Its principles are shown by fig. 13.

A water tank A, holding 10 liters, standing on the sulphur insulators C_2, was connected to a high-pressure storage cylinder of carbonic acid gas, B, also insulated with sulphur by the insulators C_1. The gas cylinder was provided with a valve E, which reduced the pressure of the gas so that the water in A could be kept under a constant pressure of e. g. 1.5 atmospheres. From A, a copper pipe H led the water out through the wall of the hut and further to the wires, at the middle of which the water jets were placed. The copper pipes had an outside diameter of 2.5 mm. Two such aggregates were arranged. They proved to be reliable and effective collector systems possessing high charging qualities, as was proved by experiments at the end of July 1919. The arrangements

were on this occasion the same as in fig. 12. The potential between the surfaces of the condenser was maintained by means of a series of storage cells, which charged the upper surface of the condenser to 39 volts during the experiment. The distance between the condenser plates was in this case made very small and did not amount to more than 16.1 cm. The result of the experiment is given in tab. 5.

Tab. 5.

Distance of collector wire from the earthed plate. in cm.	Observed difference of potential for the collector system. in volts	Calculated difference of potential for the collector wire.
12.0	29.0	29.0
13.1	31.7	31.7
8.4	20.2	20.3

As appears from tab. 5 the charging qualities of the water jet collectors were excellent, which also was to be expected considering the well-known effectiveness of collectors of this type.

At the beginning of August 1919 I had obtained a new set of sheet-copper discs covered with freshly produced polonium. Two sq. cm. of this preparation formed one collector. The new collectors were tested on Aug 5th 1919 in the usual manner. See pag. 24. The distance between the condenser plates was 65.5 cm. and the distance from the collector wire to the lower plate was 32.2 cm. The potential of the upper condenser plate was 213 volts.

The observed potential of the collectors was 101.3 volts without any noticeable difference between the different collectors, while the potential deduced from the position of the wire was 104.6 volts. It ought to be kept in mind that during the experiments the above-mentioned 2.5 mm. thick copper tubes were attached to the collector wire; only the water tank and the gas cylinder were disconnected. Through the presence of the copper pipes the capacity of the wire became greater and its drooping increased to 20 cm. The potential difference of the system thus corresponded to that of the collector-wire if it was situated 1 cm. lower than at the experiment. The difference seemed to be higher than was to be expected, especially as the manufacturer of the preparations had assured me that special efforts had been made to procure a high activity of the preparations. Some accidental fault in the insulation had probably occurred in the shape of a conducting cobweb thread or something of that kind, perhaps due to the late hour of observation, 9—11 p. m. In order to make sure of this the radium collectors were taken away from the wire, while the copper-pipes were joined to the water tank, by which means the water jet collector could be brought into

function. The potential observed for the water jet collector in the field of the condenser amounted to 109.7 volts, while the calculated one was 111.5 volts, which accordingly corresponded to a lowering of the collector wire of 0.5 cm. As on former occasions the water jet collector had showed no considerable difference (pag. 27) between the observed potential and the calculated one, it was proved by this that the comparatively great difference had been caused by some accidental defect of the insulation. A repetition of the experiment with the polonium collectors some time afterwards gave practically no difference at all between the respective collectors and the difference of potential of the system correspondend to a lowering of the collector wire amounting to 0.4 cm.

When the polonium collectors of the fixed system had been mounted almost a year and tested latest in February, they were subjected to some new tests on a fair, bright day at the end of August 1919 in order to investigate if the activity had changed. The investigations should preferably be made with the collectors attached to their respective wires as during the registration. A comparison was therefore made in the open air between the observed potential of the movable collector system during 10 minutes and that of the fixed system. To the movable system was attached 5 sq. cm. polonium, supplied and tested in August 1919, and so as a matter of fact the potential of this system ought to have been correct considering that a careful examination of the insulators and the rate of charging had been made before the tests. Tab. 6 below gives the result of the observations and it appears that the charging effect of the fixed collectors was sufficient.

Tab. 6.

Heightin metres above ground.	Fixed collectors volts.	Movable collectors volts.
3	199.2	199.6
2	135.6	136.4
1	73.1	73.5

As already mentioned freshly made polonium for the movable collectors was procured in August 1919. The preparations supplied in May of the same year had to be returned because of too weak radiating power, which was a great disadvantage, as it delayed the observations with the movable collector system. In December 1919 another 6 sq. cm. polonium was obtained for the movable system. On Dec. 17th tests were made both with these preparations and with those used up to that time in the movable system. In the case of the former 3 sq. cm. of the preparation formed one collector. The distance between the plates of the collector was 48.0 cm. and the height of the collector wire above the lower surface was 29.9 cm. The upper plate had a tension of 218 volts. Tab. 7 below gives the result of the observations.

The calculated potential difference of the collector wire was 136.2 volts. The old collectors thus corresponded to a lowering of the wire of 0.6 cm., while the new ones gave a lowering of 0.3 cm. In order to increase the charging capacity both the old collectors and the new ones were attached to the movable collector system during the observations with the movable system of collectors. These double collectors were used for the observations with the movable system to the end of June 1920.

Tab. 7.

Collector No.	Observed potential difference for the: Old collectors. volts	New collectors. volts
1	133.4	135.0
2	133.3	134.9

A test of the charging capacity of the movable collectors, which was made in June 1920, showed a certain decrease in it. The difference between the potential of the collector wire, as calculated from its position between the plates of the condenser, and the observed one corresponded to a lowering of 0,8 cm. of the wire of each collector. I thought it, however, advisable to ascertain in yet another manner if this difference between the observed potential of the wire-system and the calculated one could have any disturbing influence on observations of the potential gradient made with the movable collector system. Considering the earlier tests of the collectors such a disturbance might possibly be expected to have influenced especially the observations made during May and June 1920.

The test in question was made in the following manner. The top wire of the movable system was put at a vertical height above the level of the ground of 75 cm. The potential difference of the wire-system was observed during 10 minutes on a day with undisturbed atmospheric potential and at the same time the potential difference of the fixed collector system was recorded for the height 1 metre above the ground. The same procedure was performed with the lower wire of the movable collector system situated at a height of 75 cm. and the collector attached to it. After correction for the variation of the potential during the time of observation the two movable collectors showed practically the same potential difference to earth.

Originally it was my intention to replace the above-mentioned collectors with freshly produced polonium-preparations already on May 1st 1920, but because of delayed delivery the latter did not arrive until the end of June. In the beginning of July tests were made of the charging capacity of those new preparations. The observations were made in the same manner as the tests previously described (page 25) with the slight difference that the potential difference between the sur-

faces of the condenser was observed with the precision voltmeter for direct current of the Siemens-Halske type, No. 981628, while at some of the earlier observations the difference in question had been recorded with one of the quadrant electrometers or measured with the Wulf electrometer.

I have considered it appropriate in this context to describe the suspension arrangements for the polonium preparations (see fig. 14).

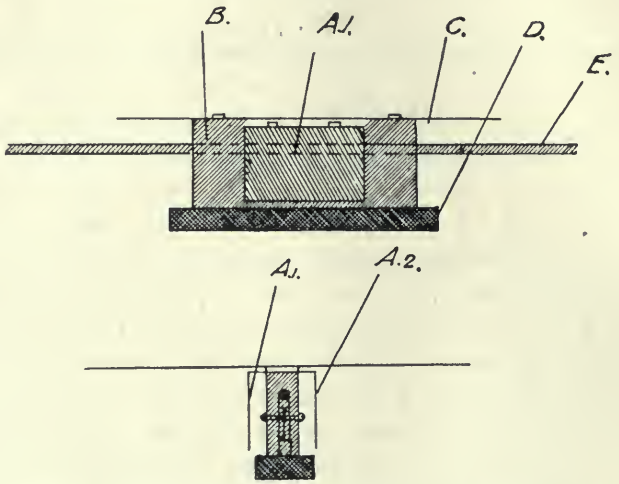

Fig. 14. Sketch showing the arrangement for suspending a polonium collector.

In a rectangular metal plate B, a groove had been sawed out in which the collector-wire E could be inserted. On each side of B were placed the two sheet-copper plates A_1 and A_2, which on their outsides, counted from the metal plate B were covered with freshly produced polonium on an area of 1 or 1.5 sq. cm. each. The plate B could swing freely round the wire E and in order to moderate the swing it was provided with the weight D. On the collectors used after July 9th 1920 the weights were placed very near to the bottom of B as shown i fig. 14. In the earlier collectors the weight was fixed a little lower, with respect to the bottom of B. If, as often happened in hard wind, the wire E got into torsion movement round its central axis, the plate B followed only slightly the swings of the collector-wire, thanks to its slight friction against E. By this means the plates A_1, A_2 were kept practically vertical during the observations. The plate B was provided with a sheet-aluminium cover, which was intended to shelter it from precipitation. It ought to be mentioned in this context that at all observations made with the movable collector system the supporting arrangements of the collectors were the same except the position of the weight D. In

the fixed wire-system, on the other hand, the collectors were fixed to the respective wires by means of screws. In case of hard wind the collectors were therefore caused to swing rapidly round the central axis of *E*. These rapid movements did not disturb the potential registrations, for the curves were very regular in spite of the rapid swings of the collectors. The position of the polonium preparations in vertical planes on both sides of the wire may have had a favourable influence in this respect, as a deflection to one side from the vertical plane caused a lowering of the charging column of one of the polonium plates, while it meant a corresponding increase of the same column of the other plate.

The results of the tests with the polonium preparations procured in June 1920 for the movable collector system are given in tab. 8. The values were obtained by the method indicated by the scheme of connections given in fig. 12. The table shows the potential of the supporting wire as calculated from its position in the condenser field and the observed potential of the same wire.

Tab. 8.

Collector number	1	2	3
Potential calculated from geometric position of the wire.	170.8	171.9	171.4
Actually observed potential of the wire system	170.5	171.7	171.3

It appears from the table that the charging rate of the wire is quite satisfactory, especially as the wire-system from having had the same potential as the earth assumed the potentials given above within the lapse of 40—50 seconds, which proved the perfect qualities of the polonium preparations.

At the first look it may be surprising that these preparations showed better charging values than some of the earlier ones. I found the reason for this fact by means of an experiment. The weight *D* (in fig. 14) was lowered 1 cm. at one of the collectors by adding a plate below the bottom of *B*. Then the collector was tested in the condenser field in the usual manner. The potential of the wire system thus became considerably lower and corresponded to a lowering of the collector wire of about 1 cm. The experiments were repeated with three other collectors and gave the same results for all of them. A certain disturbance of the field around the collector will of course be caused if the weight fixed to the collector hangs an appreciable distance below the centre line of the wire. This may also explain why the polonium collectors previously tested had always given a lower potential than that calculated for the collector wire, in spite of their being recently produced. Their weights were situated 3—4 mm. lower counted from the bottom of the plate *B* than was the case with the weight tested in tab. 8. The

disturbance caused by the weights could not have any considerable influence on the results of the observations owing to the fact that each system of collector wires had practically identical supporting arrangements for the polonium covered surfaces. The collectors tested in tab. 8 were used for all observations with the movable collector system later than July 7th 1920.

The registrations could also be disturbed through defective insulation in one of the 6 or 7 insulators that formed part of each collector system. The different sets of insulators were protected as far as possible against dust and moisture and very rarely any of the indoor insulators showed reduced effectiveness. The defects occurring on them were only accidental. Some thin cotton or cobweb thread flying in the air could sometimes form connection between the earthed case of the insulator and its conductor. Especially the out-door insulators, situated between the posts had to be inspected frequently.

By means of scraping the surface of the sulphur (in the case of older types) or by direct observation of the glassy sulphur surface[1] (of later types) one could easily detect the appearing of eventual flaws. Sometimes they occurred on an insulator the first time it was subjected to pulling strain. In such cases the insulator was at once replaced by another.

During the observations the insulation of the different collector systems was often tested. With the water jet collectors this was done in the following manner. First the rate of charge of the system in question was observed. Up to a certain moment it was kept earth-connected and then the charging began. If the final potential was then reached in shorter time than one minute the insulation was considered to be good. Thanks to the three simultaneously recording electrographs it was generally very easy to discover an insulation defect occurring in one of the collector systems. In case of slight defects of the insulation of a system sharp variations of potential were smoothed out and the curve in question showed an appearance differing from the others.

If an insulation defect was suspected the water jet collector was stopped and the system was charged by means of a positively charged glass tube to about its normal potential. Through observations of the rate of discharge of the system it could be ascertained if there really was a defect in the insulation. If there was one, the defect could be located by means of changes in the connections and further observation. On the whole the same method was employed for tests of the insulation of the polonium collectors. Their radiation was during the experiments stopped by wrapping them up cautiously first in tinfoil, then in common tissue-paper, without touching the active surfaces.

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[1] By casting the sulphur against glass plates very smooth surfaces could be obtained, which could easily be kept clean.

Most insulation defects were quite accidental and caused by spiders. This question is treated more thoroughly in another context.

Inaccuracies caused by some Disturbances in the Electric Field through the Collectors.

The water jet collectors first used in the fixed system might be suspected to cause certain disturbances in the field. The jets of the top collectors might possibly have an injurious influence on the voltage of the lower one. In August 1918, one day when the potential variations were slow, this was tested in the following manner. First the collector at 3 metres height was stopped and the system charged by means of $MgSO_4$ — batteries to the mean potential it had while in operation. The potential of the lower collectors was observed with the jets in operation during some time. No difference in deflection with the one before could be noticed. Then both the collector at 3 metres and the one at 2 metres were stopped and charged with batteries, and still no difference from the previous potential could be noticed at the lowest collector.

For the polonium collectors, on the other hand, field disturbances were excluded except for the air in the vicinity of the collector plates. As is well known the reach of the α radiation of polonium is too short to lead to any considerable disturbing effect in the field around the collector wires.

The result obtained through the search for eventual inaccuracies in the investigations is that the atmospheric electric potential gradient and its variation in different layers close to the ground can be investigated with sufficient accuracy by the methods of observation employed for this research.

The Observations.

Investigations of the atmospheric potential gradient with the apparatus described and discussed above were commenced on August 1st 1918. During one year from Aug. 1st 1918 to July 31st 1919 the potential of the three fixed collector points, at 1, 2 and 3 metres above the ground respectively, was observed. The variation with the height of the potential in the interval 0—9.5 metres was observed with the movable collector system in 125 series of observations during the time Aug. 21st 1919 to Aug. 13th 1920.

This investigation had in view an examination of the potential gradient of the layers in question in case of an even, comparatively undisturbed potential and therefore such days were left out of account on which the potential gradient was influenced by occasional meteorological phenomena such as fog, precipitation, and so on. As the period of observation only extended over two years and

the number of disturbed registrations was great, the treated material of observations is rather heterogeneous. The number of individual observations is, however, large enough to allow of general conclusions for the place of observation.

I was obliged to make this research beside my duties as assistant at the Meteorological Institution of Upsala University. Therefore I could not afford to devote too much time to direct supervision of the registration process and so a defect occurring in the recording of one of the electrographs could not always be corrected quickly enough. As the hours during which one of the three electrographs failed to record or gave a vague record have been left out of account, certain gaps have occurred in the material of observation, which to some extent have increased the heterogenity of the material.

The account of the observations will be divided into two parts, comprising firstly the observations with the fixed collector system and secondly those with the movable one.

Variation of Potential Gradient at 0—3 metres Height above the Ground according to Observations with Stationary Collector Systems.

Out of the more than 330 days on which the potential gradient had been observed I had to select, as mentioned, for my investigation such days as showed a comparatively undisturbed potential. At this selection I followed in the main the same principles as in a previous work[1] of this kind. I considered it appropriate to make the following characterization of the days that were to be treated with regard to the undisturbedness of their potential.

Character 0 = undisturbed potential. No meteorological causes of disturbance such as precipitation, fog, driving snow, and so on. No low stratus or nimbus clouds, degree of cloudiness[2] 0—3.

Character 1 = the above with the exception of the presence of low clouds and cloudiness varying from 0—10.

Character 2 = comparatively undisturbed potential, occassional inconsiderable irregularities caused by fog, driving snow, or precipitation.

The days of observation selected according to these principles could not, however, be treated without further examination with regard to certain occasional outward disturbances. There were especially two causes of disturbance to be taken into consideration, namely dust from the adjacent high-road and insulation defects caused by cobweb threads.

The disturbances caused by dust were not very considerable during 1918

[1] Harald Norinder, Kungl. Sv. Vetenskapsakademiens Handlingar. *58*. No. 4. Stockholm 1917.

[2] According to observations at the Meteorological Institution for each day at 6, 8 and 10 a. m., noon, 2, 5, 7 and 9 p. m.

thanks to the scarcity of gasoline for motor vehicles, but they often occurred in the summer of 1919 and 1920 when motor cars and motor cycles were more numerous than ever before. With regard to the observations with the movable collector system it may be mentioned that some series of observations, after the observations already had begun, had to be stopped because of occurring dust disturbances. In the winter a number of observation hours had to be left out because of disturbances through smoke from the Epidemic Hospital situated close by.

The chief disturbances were, however, caused by the indefatigable spiders, the plague of all researchers into atmospheric electricity, whose threads and webs would cause defects of the insulation in wet weather, especially during nights when there was dew. In daytime their threads were of account only in a few exceptional cases. I tried, however, to keep the systems free from cobweb threads by sweeping them repeatedly every morning and evening. In the insulator caps their existence was made a little unsafe by presence of carbide of calcium, which besides being an excellent desiccant also seemed to keep spiders out of the way by producing acetylene gas. The difficulty of always keeping the system free from spiders besides attending to my work and looking after the registration instruments will perhaps be clear from the fact that on a sunny summer day I caught about 100 spiders in two hours.

Hours of observation, during which I could suspect some defect in the insulation caused by spiders, were at once left out of account. In winter some hours of registration had also to be excluded because of long frost crystals that made the insulation defective. In order to secure a homogeneous material of observation all such hours were also left out of account that did not give a quite clear record for all the three collectors. Several hours had thus to be left out because of this reason, as the maintainance of a continuous registration requires, even for a quadrant electrograph, very careful supervision.

Calculation of Potentials from the Registration Curves.

Even in fine weather the potential of the atmospheric layers close to the ground is not constant during a long time, but varies more or less. Therefore it was considered appropriate to treat the records during a certain number of minutes of each full hour for which records were at hand that could be treated according to the principles indicated above.

The time to be treated was fixed to 11 minutes of each hour. The potential for a certain hour given below, e. g. $2^{h.}$ p. thus comprises the minute record of all the three electrographs for the minute precisely $2^{h.}$ $0^{m.}$ o'clock together with the 5 minutes immediately preceding and following.

A mean value of the potential was deduced for each such period of 11 min-

utes. When the potential was particularly even this mean value was obtained in the following manner. A glass scale with an exact millimetre-graduation was provided with a cross-rule net-work in which each square comprised 1 sq. mm. This scale was placed with the square-net over the potential record of the 11 minutes in question, which was limited by two vertical lines, one on each side of the period and both normal to the zero-line of the record. The small space between the points of registration had been filled in with light pencil lines. By means of the vertical lines and the square-net the glass scale could easily be removed so as to indicate the right ordinate mean value for the 11 minute period.

This method of reading was tested very carefully before being adopted. Several series of 11 successive minute registration points were first read directly and their mean ordinate values were calculated. Then the same arithmetical means were observed according to the method described above. In case of even registration curves the means showed practically no differences between the two methods. If the curves were fairly irregular the differences would on an average amount to $\pm$ 0.1, exceptionally $\pm$ 0.2 mm. But for curves where it would be difficult to make a reliable square estimate because of their course being irregular, I considered it more appropriate to read the 11 ordinate values of the different electrographs directly and to calculate the mean ordinate values by adding them. The mean values of the ordinates thus obtained were multiplied with the calibration constants of the respective electrographs and thus mean values were obtained of the potential differences.

The observed and calculated potential differences between the collector points at 1, 2 and 3 metres height and earth were put into tables for each used hour of observation. If these differences are called V_1, V_2, and V_3, respectively, the potential gradients of the layer in volts per metre were obtained:

$$0-1 \text{ metre} = V_1 = dv_1\,; \quad 1-2 \text{ metre} = V_2 - V_1 = dv_2\,; \quad 2-3 \text{ metre} = V_3 - V_2 = dv_3.$$

In the following the notation dv_1, dv_2 and dv_3 introduced here will be used for the potential gradients. Corrections of these gradient values for the disturbance caused by the hut and posts (see p. 21) can be introduced by multiplying the values dv_1, dv_2, and dv_3 with the factor 1.02. The difference $dv_2 - dv_1$ will be indicated by d^2v_1, and $dv_3 - dv_2$ by d^2v_2.

Before treating the observation material for dv_1, dv_2, and dv_3 more in detail, I have considered it appropriate to give in the following chapter some general remarks on the nature of the atmospheric electric field.

Some Remarks on the Atmospheric Electric Field in the Layers Nearest to the Ground.

If the air in the vicinity of the ground were devoid of ions the field would, according to the observations hitherto made, under normal conditions be directed downwards. As is well known the curvature of the earth's surface does not influence the gradient within the nearest kilometres and thus no variation of the gradient with the height would be noticeable in a field free from ions and situated near the earth's surface.

On the other hand the presence of ions will under certain conditions change the field very much. Starting from observations of the ionisation of the air and assuming certain conditions E. v. Schweidler and others have, as I have already mentioned, treated the variation with the height of the field near the ground. The solution from one point of view most complete is the one given by M. Behacker. According to his way of reasoning, which is only a slight modification of v. Schweidler's, an infinitely extended homogeneous volume of gas is situated on one side of an infinite conducting plain surface. The ground-plane occurring in Behacker's calculations can with the introduced values of the ionisation conditions of the air be considered as replaced by the earth's surface and the solution of the variation of the field force with the distance from the ground-plane can accordingly represent the conditions of the atmosphere near the ground. The results of Behacker's calculations for a primary field force at the ground-plane of 90 volts, are made clear by fig. 15.

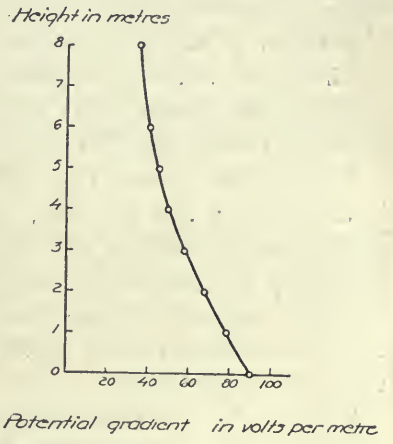

Fig. 15. Diagram showing the result of M. Behacker's calculations of height variation of potential gradient.

The diagram of fig. 15 shows that the field force decreases very rapidly with the height, and already at 8 metres approaches a limit value of only 36,6 volts. The assumptions that were made for these calculations contain, however, very simplified conditions, the gas being at rest and the ionisation constant.

These simplified conditions that were a presumption for M. Behacker's calculations are in all probability not compatible with the real ionisation state of the atmosphere, which is too variable to permit so simplified calculations as the above-mentioned.

A great many observsations have hitherto been made at different places with the Ebert ion counter as to the number of light mobile ions in the lowest at-

mospheric layers. In each c. c. has been found on an average about 700—800 pairs of ions of this kind. The number of positive ions have, according to the observations, appeared to be on marked excess and it has therefore been supposed that the resulting volume charge of light mobile ions in the lowest layers of the air should be positive. To a certain extent one must have one's doubts as to this result of the observations. Investigations by W. F. G. Swann[1] and by the author[2] show that the Ebert ion counter is impaired by a very serious defect when exposed in a positive atmospheric field without an electrostatic shield. The apparatus will in such cases give too low values of the negative ions. This characteristic of the Ebert ion counter has certainly affected many of the observation series made, and the positive excess of the light mobile ions is in reality, if it exists at all, by no means so pronounced as it seems to be.

The comparatively frequent occurrence of heavy, slow moving ions is of the greatest importance for the free charge in the atmosphere and thus for the structure of the electric field in the lowest layers of the air.

Besides light mobile ions with velocities amounting to 1.5—1.8 cm. per second in a field of 1 volt per cm., which are caught by the Ebert ion counter, there are in the atmosphere, as was first shown by P. Langevin,[3] also heavy ions with a velocity of about $0{,}0003$ cm. per second. According to Langevin's first observations the number of these heavy ions per unit of volume in the air surrounding the Eiffel tower in Paris could amount to a figure 50 times greater than that of the light mobile ions.

In spite of the great importance of the heavy ions, for instance for the structure of the atmospheric electric field, there is up to this date only a comparatively small number of data at hand with regard to these heavy ions. About 400 observations of of the number of heavy ions, extended over a period of 12 months, were made in Dublin by I. A. Mc Clelland and H. Kennedy.[4] They found a number varying between 3 200 and 60 000 per c. c. and the average was about 16 000. The number varied very considerably with the weather conditions. Unfortunately the publication of the said authors does not permit any conclusions as to the relative occurrence of positive and negative ion charges. Diverging observation data were obtained by S. G. Lusby[5] and I. A. Pollock[6]. The latter showed, besides heavy and light mobile ions, in the atmosphere also such of an intermediate velocity, while, on the contrary, Mc Clelland and Kennedy found sharp distinctions between

[1] W. F. G. Swann, Terr. Mag. *19*. 205. 1914.
[2] H. Norinder, Arkiv för Matematik, Astronomi och Fysik. *15*: 2. 1920.
[3] P. Langevin, Comp. rend. *140*. 232. 1905; Le Radium *4*. 218. 1907.
[4] I. A. Mc. Clelland and H. Kennedy, Proc. Roy. Irish. Acad. *30*. 72. 1912—13.
[5] S. G. Lusby, Roy. Soc. New. S. Wales. XLIII. 55. 1909.
[6] I. A. Pollock, Le Radium *6*, 129. 1909.

the heavy and the light types of ions and no intermediate type. The high average value for heavy ions that was found in Dublin is ascribed to the fact that the place of observation was a big industrial town. According to Pollock the average number of positive heavy ions in Sidney amounted to 1 914; of negative to 2 228, — figures that correspond to later investigations by Gockel.

Very elaborate and interesting researches on the occurrence of heavy ions were made by A. Gockel[1] at Freiburg. He agrees with Pollock and believes that there are both heavy (Langevin) and intermediate ions. During times of observation when there was no precipitation the average number of heavy and intermediate ions per c. c. was 1 785 positive and 1 828 negative ones. Accordingly the number of heavy ions did not, as Langevin had found, amount to 50 times that of light mobile ions, but to twice or three times their number. The highest number was found for negative ions and amounted to about 7 800 per c. c. When the weather was dusty and hazy the number of negative ions could amount to 2 900 per c. c.; of positive to 2 580. Very high numbers of negative ions were observed by Gochel on calm and clear winter days when 2 600 per c. c. were obtained.

The heavy negative ions occur, according to Gockel's investigations especially under hazy weather conditions, which he declares as dependent on the greater specific velocity of the negative ions, because of which they are more frequently absorbed by small dust or water particles. According to Langevin and Moulin[2] there exists an inverse ratio between heavy and light ions in the air. A great number of heavy ions are accompanied by a small number of light ones and vice versa. Gockel points out that in weak wind one can thus expect an excess of heavy ions. In a hard wind, on the contrary, the light ions are in majority, and he refers to observations that confirm this supposition.

The relative occurrence of ions in the atmosphere, both heavy, intermediate, and light ones has an essential and fundamental importance for the structure of the atmospheric electric field in the layers nearest the ground, which to some extent is clear already from the account given on page 2. If v denotes the potential of the electric charges active in a certain atmospheric layer, h the height, and ρ the free charge, we get according to Poisson's wellknown theorem

$$\frac{d^2v}{dh^2} = -4\pi\rho \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Theoretically the potential gradient $\frac{dv}{dh}$ increases with h for negative ρ, but decreases for positive, and is constant when ρ is zero.

[1] A, Gockel, Neue Denkschr. d. Schweiz. Naturf. Ges. LIV : 1. 16. 1917.

[2] P. Langevin and Moulin. Le Radium. 218. 1907.

If observations of $\frac{d^2v}{dh^2}$ could be made in the open air, it would accordingly be possible to calculate the free charge of the atmosphere from the values obtained. Such an application of Poisson's theorem offers itself temptingly to atmospheric observations of $\frac{dv}{dh}$ and has also been recommended by many authors. This theorem was also employed all through in Daunderer's above-mentioned investigations. He observed the potential at the heights 0, 1, and 2 metres above the ground and thus obtained two values of $\frac{dv}{dh}$ for the height interval used. He then assumed identity between the differences of $\frac{dv}{dh}$ and $\frac{d^2v}{dh^2}$ in Poisson's equation and so he could calculate ρ. For this calculation he assumed the following relation as prevailing for the variation with the height of the potential v in the interval of observation: $v = ah - bh^2$ where a and b were constant.

For divers reasons I have not found it possible to treat my observations by deductions with Poisson's theorem in individual cases. Firstly such an application of equation (2) presumes such a distribution of the free electric charge in the neighbourhood of the observation points that the horizontal components of the field force can be neglected. The validity of such a presumption can only be tested by a direct observation of the horizontal components in the whole interval of observations, (0 to 9 metres), a research that I have not undertaken. Secondly the observations of the height variation of the potential gradient indicate comparatively great irregularities with regard to the distribution of observation points. When the whole interval of observations comprises a comparatively small number of observation points, as was the case in my work, one must proceed with the greatest caution in applying Poisson's theorem. In the mean values and in the diagram of them, on the contrary, the irregularities were eliminated if the number of observations was chosen sufficiently great. As a preliminary approximation of the free charge of the atmosphere I therefore thought it appropriate to apply Poisson's theorem in certain cases to the mean values of the variation of the potential gradient with the height. Only by applying Poisson's equation the observations of the variation of the gradient could be compared to values of the free charge of the atmosphere obtained through observations with the use of ion counters.

An observed excess of the charge of negative heavy ions, for instance amounting to $0._{15}$ E. S. U. per cubic metre, would according to Poisson's theorem cause an increase of the potential gradient amounting to about 5.7 volts for an interval of 1 metre. Values of the free charge of this order of magnitude were observed

by A Gockel[1] as mean values in hazy weather. Gockel's observations were, however, made by means of a collector that was placed in an opening made in a window, and accordingly they are not unreservedly referable to the open atmosphere, as the distribution of the ions may possibly have been disturbed by the wall of the house and thus be different from the one prevailing at some metres' distance from a vertical wall.

Sometimes very considerable variations of the gradient may be expected due to the discontinuity of the distribution of ions in the vertical direction and connected with a marked horizontal layering of the air. It is well known that under certain meteorological conditions the air in the immediate vicinity of the ground has a tendency to spread itself into stable layers one above the other, where the stability depends upon an increase of temperature in the vertical direction. The layers nearer to the ground are in such cases coldest and warmer air floating above them. In the very border between two layers of air with different temperatures there also occur discontinuities in the humidity of the air. By means of the diffusion of water vapour from a warm layer floating above a cold one, the air can be supersaturated at the boundary between the warm and cold layers, and a condensation of small drops takes place. If these drops are sufficiently numerous and big enough it can be noticed with the naked eye as fog or haze. Especially in winter a horizontal stratification of this kind can often be noticed in the shape of comparatively thin layers of haze. In certain cases they will spread themselves over many miles especially from large cities where the smoke gases supply a great number of condensation nuclei, which are favourable to a strong development of the grey or yellowish brown haze that can often be noticed in winter near large cities. It is often difficult to notice these layers of haze against the blue sky, as they diminish the visibility of the air only to a slight extent in the immediate vicinity of the ground. But if observed in winter from elevated points in a white snow-covered landscape they are easy to recognize. If the haze layers are exposed to the rays of the sun, the nearest atmospheric layers are warmed and the haze layer will rise. On the other hand, it can also get into a sinking movement through being cooled. This has been found to be the case with larger layers of haze that have been observed during long balloon ascents, and there are no reasons why movements of the same kind should not take place, on a small scale, with thin layers near the ground, where the conditions are favourable for a horizontal stratification of the air. Especially on cloudless days in winter the air immediately above the surface of the snow can, under anticyclonic weather conditions, be mingled with very small drops of water or ice particles. Often the layer of haze does not extend more than a few metres. Observations of the potential gradient near the ground in such layers will as a

[1] Loc cit. p. 16.

rule show a considerable variation in the values of the gradient, which finds an explanation in the great ion absorption of the haze particles. Thanks to the general current of ions a thin horizontal layer of particles in suspension, situated at a height of a few metres above the ground, can very considerably modify an originally homogeneous field, where neither negative nor positive ions primarily are in excess. Such observations with regard to haze layers at greater heights have been made from balloons by F. Linke.[1] He has observed the existence of very strong variations of the potential when crossing a layer of haze, at the under side a great increase, inside the layer almost constant potential, and at the upper side a great decrease of the gradient. He has also given an explanation of the amassing of ions.

The exterior positive field with the direction towards earth causes at the upper side of a layer of haze an amassing of positive ions streaming into it and at the under side of negative ones sometimes streaming upward from the earth's surface. The amassing does not from the beginning necessarily imply the existence of heavy ions, but the latter may simply be formed in the layer by means of a combination of light ions and neutral nuclei. According to F. Linke there often exist excessive positive charges in a layer of haze. As he has pointed out the upper side of the layer is fed with ions coming in from outside (from a large volume), while at the under side the negative ions come in from the space between the layer and the earth's surface (from a limited volume). At a great distance a charged layer with excess of positive ions would accordingly directly work as a positively charged plate, and at a certain distance the field would, because of its charge, show a constant gradient, while only in its neighbourhood a noticeable variation of the gradient would be perceivable.

Certain observations in the following, in which the gradient showed a variation that was many times greater than the one found to be normal, may find an explanation if it is taken into consideration that also in the lowest atmospheric layers there must exist ion-absorbing layers. Of course the process of absorption itself need not necessarily have taken place in the immediate vicinity of the collectors. Because of vertical replacings in the atmosphere only the remainders of such layers with ion absorption will sometimes reach the point of observation.

The heavy, slow moving ions in the lowest atmospheric layers have been considered, as mentioned above, to be formed by means of an absorption of light, mobile ones by neutral nuclei. The excess of negative charge was then considered as caused by the greater specific velocity of light mobile negative ions compared to that of the corresponding positive ones.

According to my opinion, there is, however, occasionally another explanation to be found of this excess of negative heavy ions. We presume that there is

[1] F. Linke, Abh. d. Kgl. Ges. d. Wiss. Göttingen. N. F. III : 5. 1904.

calm in the layers nearest to the ground, for instance 0—20 metres, and that in the primary state practically the same number of positive and of negative heavy ions have been formed by the absorption round neutral nuclei..

The diameter of those nuclei (small water drops or ice crystals) may be taken to be about 2×10^{-5} cm.[1] We presume further that in the primary state after the process of absorption there is a homogeneous distribution of positive and negative ions. Both the positive and the negative heavy ions fall under the action of gravity and will get a velocity downwards the earth's surface that may be found by Stokes's formula as corrected by M. Reinganum[2] or by R. A. Millikan.[3]

Through the direction of the normal electric field of the atmosphere the heavy positive ions will get a velocity which must be added to their velocity in the gravitation field, while in the case of the heavy negative ions the gravitation velocity will work in the opposite direction to the velocity caused by the electric field. The velocity of the heavy negative ions in the atmospheric field will accordingly become considerably smaller than that of the corresponding positive ions. In the case when there is a certain wind velocity in the layer in question the above-mentioned velocities will also have to be added to those which the heavy ions will get by floating with the air-streams. The conditions will of course in this case become considerably more complicated than in the case of calm weather. If we presume that the absorption layers of the heavy ions occupy the volume from the ground and for instance some tens of metres upwards, the different velocities that the negative and the positive heavy ions will assume in the field may easily cause an excess of negative ion charge.[4]

When we consider the facts pointed out in this chapter it is accordingly not to be expected as a rule that the potential gradient will decrease with the height in the lowest layers of the air, more likely the reverse will happen.

Discussion of the Observations of the Gradient in the Interval 0—3 metres.

Tab. 9 pag. 44 shows values of the potential gradient in volts pr metre dv_1, dv_2, and dv_3 deduced from the registrations obtained with the fixed collector system. In the first vertical column of the table are given the dates of observation and the character of the gradient with regard to disturbances. For certain calculations I have considered it appropriate to fill certain gaps in the observation material by means of linear interpolation as is often done in meteorological observation series. The interpolation has only taken place in the horizontal

[1] See A. Wegener: Thermodynamik der Atmosphäre p. 251. Leipzig 1911.
[2] M. Reinganum, Verh. d. Deutsch. phys. Ges. *12*. 1025. 1910
[3] R. A. Millikan, Phys. Rev. *32*. 349. 1911
[4] The charge of the accumulated heavy negative ions causes, however, a negative field acting in the opposite direction against the outer positive field. Because of this the conditions are somewhat modified.

Tab. 9. **Individual Hourly Values of Potential Gradient at 0—1** dv_1,

1918		1 a. m.	2	3	4	5	6	7	8	9	10	11 a.m.
2 4.8	dv_1	8	5	10	21	13	35	—	51	55	—	46
	dv_2	9	9	11	27	16	39	—	35	44	—	53
	dv_3	11	3	19	15	3	19	—	−14	21	—	36
2 11.8	dv_1	8	14	9	18	20	25	—	61	38	—	51
	dv_2	16	19	31	30	27	29	—	56	35	—	41
	dv_3	13	7	−8	11	14	20	—	54	42	—	40
1 12.8	dv_1	—	—	—	—	—	—	—	—	—	41	—
	dv_2	—	—	—	—	—	—	—	—	—	46	—
	dv_3	—	—	—	—	—	—	—	—	—	21	—
1 24.8	dv_1	40	34	24	21	26	31	33	38	33	27	26
	dv_2	39	29	20	18	24	26	26	31	26	33	32
	dv_3	39	33	25	22	30	30	35	42	34	24	22
1 26.8	dv_1	34	23	24	20	25	18	23	—	37	44	39
	dv_2	35	26	23	22	27	16	16	—	39	41	30
	dv_3	35	28	30	19	27	21	23	—	43	57	43
1 30.8	dv_1	—	—	—	—	—	—	—	—	—	—	19
	dv_2	—	—	—	—	—	—	—	—	—	—	12
	dv_3	—	—	—	—	—	—	—	—	—	—	44
2 5.9	dv_1	35	33	30	29	45	33	41	51	57	61	—
	dv_2	29	34	37	35	47	31	38	52	55	54	—
	dv_3	28	26	23	23	35	29	33	49	56	63	—
0 7.9	dv_1	35	31	33	39	36	33	42	36	36	35	38
	dv_2	39	36	36	42	40	38	45	39	38	38	39
	dv_3	42	34	35	43	32	32	43	16	41	31	41
2 8.9	dv_1	29	39	27	61	42	34	—	—	—	49	55
	dv_2	33	53	39	74	50	39	—	—	—	32	28
	dv_3	41	62	38	77	54	13	—	—	—	70	84
2 15.9	dv_1	56	51	50	46	42	38	30	25	—	—	—
	dv_2	53	49	45	44	36	35	28	15	—	—	—
	dv_3	62	57	52	53	50	43	39	37	—	—	—
1 22.9	dv_1	—	—	—	—	—	—	—	—	—	—	—
	dv_2	—	—	—	—	—	—	—	—	—	—	—
	dv_3	—	—	—	—	—	—	—	—	—	—	—
0 26.9	dv_1	43	44	38	43	44	40	38	—	—	—	57
	dv_2	20	26	9	17	26	22	9	—	—	—	36
	dv_3	18	27	46	40	27	18	25	—	—	—	94
2 11.10	dv_1	67	74	66	24	—	33	47	88	—	—	105
	dv_2	69	77	66	22	—	40	49	89	—	—	115
	dv_3	63	68	50	23	—	26	35	42	—	—	77
2 14.10	dv_1	—	—	—	—	—	—	—	—	—	—	—
	dv_2	—	—	—	—	—	—	—	—	—	—	—
	dv_3	—	—	—	—	—	—	—	—	—	—	—

1—2 = dv_2, and 2—3 = dv_3 Metres above Ground. Upsala 1918—1919.

noon	1 p. m.	2	3	4	5	6	7	8	9	10	11 p. m.	midn.
46	47	50	—	—	—	—	—	—	—	43	40	26
55	55	55	—	—	—	—	—	—	—	45	40	24
25	23	20	—	—	—	—	—	—	—	28	21	12
58	—	56	53	49	39	49	—	65	41	25	—	—
53	—	51	45	43	38	50	—	66	58	38	—	—
42	—	36	33	28	26	30	—	46	45	49	—	—
—	44	54	49	56	47	36	27	31	11	24	25	30
—	45	59	56	58	50	48	41	45	29	32	36	36
—	22	31	29	34	25	25	17	23	19	18	18	16
20	24	—	—	24	27	24	26	29	21	18	20	21
18	19	—	—	26	30	24	28	34	26	24	31	29
13	16	—	—	22	27	21	24	27	24	21	26	21
35	38	—	—	—	—	—	—	—	—	39	37	21
29	34	—	—	—	—	—	—	—	—	34	39	30
44	47	—	—	—	—	—	—	—	—	39	51	53
—	34	37	—	36	—	—	42	41	52	52	44	—
—	19	35	—	38	—	—	44	40	35	50	52	—
—	52	46	—	45	—	—	51	55	77	58	48	—
—	—	—	—	—	—	—	—	44	54	52	57	44
—	—	—	—	—	—	—	—	46	53	52	61	38
—	—	—	—	—	—	—	—	31	41	39	50	29
—	—	—	—	36	32	17	33	32	35	31	36	40
—	—	—	—	44	35	19	33	33	40	31	38	46
—	—	—	—	45	37	28	33	27	26	32	54	51
48	45	48	31	56	12	7	42	49	30	30	36	29
27	33	47	33	52	23	15	52	74	64	47	52	33
71	60	45	21	42	3	—3	25	31	13	21	30	48
23	24	37	29	41	—	—	—	62	66	66	57	46
20	18	33	25	32	—	—	—	51	57	66	65	52
27	19	36	31	48	—	—	—	56	64	74	68	57
—	55	58	59	59	59	68	—	74	53	39	—	—
—	44	43	50	52	50	62	—	70	93	76	—	—
—	14	9	35	41	41	42	—	59	62	39	—	—
53	67	68	71	69	62	66	79	75	60	59	—	—
38	55	54	63	77	69	71	82	79	66	63	—	—
57	66	59	62	60	55	58	73	66	55	42	—	—
101	109	118	112	86	46	37	28	—	47	54	86	55
108	115	120	115	85	43	34	30	—	44	59	100	67
81	85	71	58	28	42	37	26	—	25	41	83	60
—	—	—	76	46	73	39	90	87	73	38	19	25
—	—	—	62	45	74	43	90	90	78	46	22	17
—	—	—	97	57	71	51	103	93	66	47	21	35

1918		1 a. m.	2	3	4	5	6	7	8	9	10	11 a. m.
2 15.10	dv_1	23	33	26	32	34	49	64	82	—	93	—
	dv_2	20	27	20	22	23	37	60	68	—	90	—
	dv_3	28	33	25	28	25	28	12	17	—	48	—
0 6.11	dv_1	—	—	—	—	—	60	50	56	64	54	50
	dv_2	—	—	—	—	—	47	39	35	42	39	41
	dv_3	—	—	—	—	—	30	46	11	— 6	48	70
0 20.11	dv_1	—	—	—	—	—	—	—	—	—	- -	—
	dv_2	—	—	—	—	—	—	—	—	—	—	—
	dv_3	—	—	—	—	—	—	—	—	—	—	—
1 23.11	dv_1	—	—	—	—	—	—	—	—	—	—	—
	dv_2	—	—	—	—	—	—	—	—	—	—	—
	dv_3	—	—	—	—	—	—	—	—	—	—	—
2 24.11	dv_1	26	9	27	14	24	19	19	37	39	19	52
	dv_2	29	18	45	34	51	30	35	38	16	35	63
	dv_3	1	— 4	— 8	— 5	13	— 5	5	9	4	— 2	14
2 10.12	dv_1	—	—	—	—	—	—	—	—	—	—	—
	dv_2	—	—	—	—	—	—	—	—	—	—	—
	dv_3	—	—	—	—	—	—	—	—	—	—	—
2 11.12	dv_1	34	28	24	28	31	35	42	67	47	47	46
	dv_2	32	26	17	26	33	33	39	65	52	36	45
	dv_3	66	62	49	54	50	69	82	94	76	88	82
1 12.12	dv_1	44	25	18	17	19	26	22	28	61	50	81
	dv_2	57	18	— 2	1	17	26	42	41	54	64	94
	dv_3	71	56	57	46	38	35	53	69	105	86	134
2 13.12	dv_1	33	28	28	35	71	46	34	50	66	47	39
	dv_2	33	32	25	38	73	42	35	44	67	44	35
	dv_3	52	43	56	55	94	67	62	71	86	60	46
2 15.12	dv_1	19	11	59	—	14	—	11	26	—	38	54
	dv_2	10	6	58	—	4	—	23	9	—	35	43
	dv_3	46	34	97	—	42	—	48	48	—	86	96
1919 2 23.1	dv_1	49	37	40	31	54	57	43	70	118	114	156
	dv_2	66	30	44	32	52	52	44	72	131	123	171
	dv_3	68	53	57	64	76	61	51	89	165	148	177
1 24.1	dv_1	57	54	77	71	63	59	71	88	—	—	136
	dv_2	60	58	90	72	58	52	72	89	—	—	170
	dv_3	89	60	98	89	82	90	85	115	—	—	173
2 29.1	dv_1	56	23	41	23	72	88	84	128	137	135	—
	dv_2	85	30	16	30	89	97	96	152	159	154	—
	dv_3	68	4	73	22	68	87	90	138	147	151	—
2 31.1	dv_1	58	76	66	—	—	—	—	—	—	112	138
	dv_2	100	110	78	—	—	—	—	—	—	140	168
	dv_3	107	118	82	—	—	—	—	—	—	130	130
1 3.2	dv_1	58	56	25	45	66	48	70	86	84	95	62
	dv_2	86	78	27	46	76	51	93	103	112	116	99
	dv_3	62	76	15	40	64	31	82	93	55	101	67

noon	1 p. m.	2	3	4	5	6	7	8	9	10	11 p.m.	midn.
98	67	86	83	96	70	120	—	98	79	69	20	19
24	67	87	78	89	69	114	—	54	44	50	17	14
42	29	83	56	53	36	55	—	155	112	70	27	31
53	57	65	62	63	86	81	87	80	83	77	79	69
52	68	75	75	72	103	96	90	81	87	82	79	67
63	63	74	68	68	78	76	74	45	48	34	25	18
69	70	87	78	124	97	127	151	89	90	62	54	33
17	−32	−51	9	98	103	126	175	97	90	64	59	34
163	262	283	202	177	121	165	226	140	119	45	60	29
—	140	153	150	110	73	67	63	102	73	77	49	27
—	170	182	170	114	80	65	55	107	82	87	66	49
—	168	191	182	125	72	50	52	100	73	78	36	−5
78	87	106	115	51	59	92	—	—	—	—	—	—
95	113	140	117	55	52	74	—	—	—	—	—	—
62	82	125	177	70	50	62	—	—	—	—	—	—
—	—	—	68	50	44	64	58	14	44	52	40	51
—	—	—	57	34	48	68	57	10	45	58	49	54
—	—	—	139	109	67	97	103	54	59	72	70	78
42	—	—	—	—	70	—	—	109	73	68	51	40
49	—	—	—	—	71	—	—	133	89	76	51	51
63	—	—	—	—	120	—	—	184	130	114	70	64
46	65	—	—	80	99	104	112	—	81	71	72	41
53	93	—	—	73	121	129	143	—	84	75	76	36
74	133	—	—	118	144	157	160	—	110	100	113	60
46	47	47	—	—	57	57	65	77	72	45	47	52
42	61	45	—	—	48	62	62	84	70	39	58	54
61	68	78	—	—	99	121	90	102	96	70	80	75
49	38	50	51	35	—	—	38	28	31	33	—	30
44	28	49	31	26	—	—	26	17	12	24	—	19
96	74	78	70	58	—	—	33	6	10	45	—	33
134	—	—	—	—	111	112	188	149	122	37	42	44
160	—	—	—	—	103	125	222	160	126	26	48	35
171	—	—	—	—	106	140	268	210	167	32	49	56
—	156	153	163	—	166	36	128	94	55	84	79	38
—	186	181	187	—	189	39	180	119	67	105	94	48
—	203	193	215	—	232	68	150	113	66	110	110	64
—	—	154	128	75	92	—	58	115	95	51	57	—
—	—	209	134	90	124	—	93	151	133	75	80	—
—	—	198	173	98	137	—	98	218	171	61	76	—
158	162	113	114	—	—	—	—	—	—	—	—	—
172	178	152	158	—	—	—	—	—	—	—	—	—
162	165	128	132	—	—	—	—	—	—	—	—	—
64	123	92	79	101	81	89	117	97	125	—	74	64
92	150	105	86	108	92	88	121	110	131	—	83	59
78	130	98	84	109	101	109	119	114	122	—	58	19

1919		1 a.m.	2	3	4	5	6	7	8	9	10	11 a.m.
2 4.2	dv_1	51	41	43	37	51	43	59	56	78	45	48
	dv_2	44	39	40	39	46	30	62	45	87	59	68
	dv_3	7	1	−7	−3	5	3	50	41	64	20	22
0 8.2	dv_1	—	—	—	—	—	—	—	—	—	—	—
	dv_2	—	—	—	—	—	—	—	—	—	—	—
	dv_3	—	—	—	—	—	—	—	—	—	—	—
1 9.2	dv_1	37	29	26	27	25	32	40	44	57	64	59
	dv_2	42	36	40	38	36	44	54	66	91	107	89
	dv_3	−15	−18	−22	−21	−23	−2	12	21	40	68	76
1 10.2	dv_1	37	33	28	47	33	54	66	69	75	80	99
	dv_2	37	21	43	34	20	36	51	80	92	105	129
	dv_3	18	25	23	15	4	26	36	51	65	80	78
1 11.2	dv_1	59	51	50	—	—	—	—	115	89	88	74
	dv_2	52	49	43	—	—	—	—	124	96	87	90
	dv_3	78	76	58	—	—	—	—	114	115	125	98
1 13.2	dv_1	62	59	36	44	57	67	74	49	—	87	98
	dv_2	69	50	45	45	52	60	66	49	—	98	114
	dv_3	71	57	39	42	67	77	81	59	—	109	132
1 14.2	dv_1	38	32	—	44	45	52	65	70	76	84	82
	dv_2	33	33	—	42	40	46	53	69	77	84	76
	dv_3	50	48	—	68	65	58	92	101	102	114	130
1 15.2	dv_1	90	80	87	65	—	104	93	—	—	—	—
	dv_2	84	69	75	63	—	93	82	—	—	—	—
	dv_3	110	86	96	87	—	125	104	—	—	—	—
1 16.2	dv_1	59	51	48	48	37	60	59	98	101	124	172
	dv_2	46	44	34	29	16	42	37	89	90	116	167
	dv_3	64	66	63	60	56	65	86	146	143	180	246
2 19.2	dv_1	64	70	52	54	50	63	73	131	—	—	89
	dv_2	48	58	44	44	37	43	55	100	—	—	72
	dv_3	18	70	18	65	66	82	89	167	—	—	130
2 20.2	dv_1	78	142	84	115	108	143	117	119	144	126	—
	dv_2	49	98	58	87	83	124	104	114	133	115	—
	dv_3	107	174	115	157	158	205	168	172	199	176	—
2 27.2	dv_1	94	125	—	—	—	—	—	—	—	135	114
	dv_2	88	123	—	—	—	—	—	—	—	126	121
	dv_3	130	181	—	—	—	—	—	—	—	225	166
2 28.2	dv_1	42	24	14	16	20	65	81	106	94	—	—
	dv_2	36	28	26	21	23	63	81	113	114	—	—
	dv_3	53	51	39	64	77	125	132	171	160	—	—
1 1.3	dv_1	23	31	13	28	39	36	36	44	—	—	—
	dv_2	37	46	25	39	50	43	40	50	—	—	—
	dv_3	31	33	11	34	43	38	34	50	—	—	—
0 4.3	dv_1	59	72	56	53	50	58	63	59	59	46	53
	dv_2	19	42	33	31	28	35	46	40	55	36	43
	dv_3	77	88	62	64	63	72	74	47	62	43	53

noon	1 p. m.	2	3	4	5	6	7	8	9	10	11 p.m.	midn.
28	25	84	74	69	94	62	106	—	81	44	44	36
28	18	84	87	68	121	52	110	—	96	63	68	65
13	± 0	76	80	38	121	51	120	—	68	28	25	5
—	—	—	—	—	—	89	74	66	58	58	45	40
—	—	—	—	—	—	139	92	107	70	81	64	60
—	—	—	—	—	—	122	90	88	53	20	3	1
70	—	—	—	—	—	118	118	105	76	—	—	38
112	—	—	—	—	—	104	96	82	54	—	—	38
83	—	—	—	—	—	116	126	99	62	—	—	19
116	—	—	—	—	—	—	—	92	98	67	—	59
154	—	—	—	—	—	—	—	104	113	82	—	64
115	—	—	—	—	—	—	—	82	112	83	—	96
80	75	78	94	87	61	75	66	75	73	67	—	56
86	84	88	91	101	57	70	57	68	72	56	—	51
114	101	98	124	131	97	124	81	102	90	84	—	104
112	135	132	—	—	—	—	—	62	66	59	49	37
194	205	210	—	—	—	—	—	55	63	50	46	48
161	183	208	—	—	—	—	—	85	78	102	83	64
67	99	115	129	129	—	—	144	129	132	—	—	—
61	90	112	121	118	—	—	129	121	120	—	—	—
109	156	166	177	182	—	—	193	179	184	—	—	—
—	—	—	109	107	100	101	100	106	100	87	66	63
—	—	—	84	99	90	99	95	102	95	79	57	51
—	—	—	121	140	122	119	122	126	122	111	77	75
—	—	—	—	94	85	—	150	163	138	74	74	61
—	—	—	—	97	79	—	152	159	152	87	79	60
—	—	—	—	109	89	—	183	182	174	77	56	44
104	152	127	139	117	130	173	131	198	205	101	171	97
92	144	125	128	113	125	175	129	162	187	77	137	75
129	204	162	161	147	167	244	173	222	253	136	191	128
—	—	94	48	26	39	28	43	51	49	48	66	25
—	—	91	49	16	34	14	32	40	40	36	48	13
—	—	106	45	34	51	39	51	64	67	78	76	28
85	111	97	111	99	82	97	118	204	161	97	103	58
93	118	102	114	101	89	113	129	223	163	102	109	55
106	128	112	139	119	104	126	142	267	203	121	124	76
—	—	82	118	—	—	55	51	49	38	28	35	38
—	—	121	141	—	—	65	66	61	55	41	52	53
—	—	206	— 8	—	—	80	62	53	49	30	32	37
—	—	—	—	—	66	61	75	74	74	67	—	49
—	—	—	—	—	68	61	77	81	77	69	—	44
—	—	—	—	—	80	74	93	88	61	56	—	22
57	60	57	60	59	74	95	123	96	81	79	68	63
56	62	57	62	55	66	71	121	96	81	77	63	60
43	43	55	56	56	77	107	136	103	83	80	67	65

1919		1 a. m.	2	3	4	5	6	7	8	9	10	11 a. m.
0 5.3	dv_1	54	53	54	56	—	—	—	72	85	92	—
	dv_2	54	52	51	47	—	—	—	73	93	97	—
	dv_3	55	54	54	54	—	—	—	73	87	100	—
1 6.3	dv_1	49	49	45	46	45	53	64	73	99	106	103
	dv_2	33	32	31	36	29	55	70	74	104	121	128
	dv_3	47	59	43	73	54	73	79	103	139	141	135
1 10.3	dv_1	53	51	42	41	35	36	44	47	47	59	71
	dv_2	66	60	47	49	42	41	45	47	57	67	75
	dv_3	69	61	50	48	38	38	51	49	62	72	81
1 13.3	dv_1	44	46	44	40	102	59	84	102	147	102	102
	dv_2	55	42	47	48	104	70	94	118	181	124	118
	dv_3	32	44	47	44	113	58	92	122	161	121	117
1 14.3	dv_1	46	35	32	33	35	41	80	73	60	22	19
	dv_2	55	47	40	43	50	54	92	85	64	40	31
	dv_3	38	29	28	29	27	40	83	81	58	22	15
1 15.3	dv_1	47	41	32	33	62	47	69	—	—	—	—
	dv_2	58	46	39	40	68	48	89	—	—	—	—
	dv_3	43	32	30	31	72	67	65	—	—	—	—
2 16.3	dv_1	81	44	42	28	48	51	36	149	188	158	105
	dv_2	76	40	34	23	38	44	36	172	198	165	104
	dv_3	91	45	44	31	50	53	48	196	257	198	111
2 17.3	dv_1	71	64	68	61	59	61	70	70	62	73	54
	dv_2	73	65	64	54	51	57	67	66	66	76	56
	dv_3	71	66	71	65	61	68	69	103	68	88	65
2 19.3	dv_1	43	46	42	49	—	—	95	—	—	101	84
	dv_2	35	38	38	39	—	—	88	—	—	103	83
	dv_3	61	63	62	84	—	—	143	—	—	143	116
1 21.3	dv_1	28	30	24	30	43	89	59	—	32	103	72
	dv_2	11	11	3	12	28	89	55	—	25	101	70
	dv_3	49	50	45	61	77	129	88	—	44	135	91
1 22 3	dv_1	28	34	27	32	23	30	—	—	—	—	—
	dv_2	11	18	16	15	— 9	12	—	—	—	—	—
	dv_3	54	57	55	71	75	83	—	—	—	—	—
(2 25.3)	dv_1	63	58	55	58	49	50	57	80	101	104	94
	dv_2	41	35	28	40	24	21	29	57	91	107	101
	dv_3	140	139	146	146	145	138	154	193	217	206	167
1 26.3	dv_1	55	58	57	51	58	79	99	—	—	167	171
	dv_2	62	60	59	55	58	76	97	—	—	188	194
	dv_3	91	105	103	90	107	141	127	—	—	221	209
2 2.4	dv_1	59	65	61	63	67	71	90	79	49	72	71
	dv_2	118	101	90	79	70	82	86	81	98	87	91
	dv_3	143	142	121	113	124	127	137	127	112	122	116
2 5.4	dv_1	46	46	35	58	52	81	67	—	—	—	—
	dv_2	45	42	34	51	50	82	80	—	—	—	—
	dv_3	73	83	65	82	71	96	75	—	—	—	—

noon	1 p. m.	2	3	4	5	6	7	8	9	10	11 p. m.	midn.
—	116	124	116	121	171	89	151	91	104	100	63	60
—	133	135	117	122	175	87	153	83	96	89	63	53
—	141	153	134	142	198	113	192	107	123	99	75	64
136	147	148	99	130	174	183	114	182	140	144	113	165
163	169	167	103	124	169	185	111	167	150	149	118	183
262	179	174	117	157	202	216	130	205	164	160	130	193
89	83	95	54	59	—	83	84	84	67	63	59	54
89	84	90	57	65	—	87	74	88	63	66	70	51
120	93	118	65	69	—	99	99	101	85	74	52	62
96	90	99	117	97	80	102	118	—	103	89	68	55
127	102	114	128	103	78	105	124	—	113	97	76	61
93	94	109	139	117	95	121	135	—	119	85	60	45
28	44	73	51	71	83	90	85	108	135	112	70	48
38	70	86	59	82	89	100	96	125	147	135	76	57
27	49	76	51	85	91	103	92	125	155	103	62	35
—	—	—	—	—	—	—	—	136	156	117	132	78
—	—	—	—	—	—	—	—	137	151	116	130	73
—	—	—	—	—	—	—	—	153	162	117	147	76
81	76	90	88	70	91	95	106	85	74	95	94	78
82	73	82	85	63	82	91	100	80	73	92	92	73
86	73	87	90	64	90	98	110	94	76	93	96	81
56	56	43	35	73	90	94	94	123	70	75	81	46
63	55	46	30	74	83	93	92	131	64	72	83	37
58	60	56	33	83	102	113	112	137	81	95	112	61
94	93	87	85	93	95	71	93	68	79	73	85	81
102	82	78	88	92	90	56	84	60	72	66	83	79
114	109	99	105	115	108	85	128	97	110	99	100	97
36	36	51	56	46	—	46	32	51	57	29	32	24
31	30	43	44	33	—	35	19	44	46	17	18	12
38	36	65	56	50	—	53	37	61	70	43	51	46
151	121	136	165	153	153	129	140	139	133	124	121	97
164	133	140	175	160	157	135	144	143	135	132	121	98
172	131	155	207	181	181	154	161	164	150	137	134	105
93	111	—	—	—	—	—	—	—	—	—	—	—
99	128	—	—	—	—	—	—	—	—	—	—	—
164	175	—	—	—	—	—	—	—	—	—	—	—
161	—	—	—	152	—	116	132	—	—	100	87	84
186	—	—	—	169	—	124	141	—	—	110	106	93
187	—	—	—	186	—	124	159	—	—	114	91	99
55	71	87	87	—	—	—	—	—	—	—	—	—
94	111	108	86	—	—	—	—	—	—	—	—	—
105	115	136	125	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	159	153	153
—	—	—	—	—	—	—	—	—	—	171	165	165
—	—	—	—	—	—	—	—	—	—	169	172	174

1919		1 a. m.	2	3	4	5	6	7	8	9	10	11 a.m.
2 21.4	dv_1	35	40	33	32	26	30	36	39	54	49	48
	dv_2	34	41	30	37	29	30	43	49	62	60	64
	dv_3	51	55	58	56	60	56	53	58	71	71	65
1 22.4	dv_1	35	46	45	35	41	46	46	58	59	53	75
	dv_2	38	51	38	33	43	50	53	69	80	78	87
	dv_3	61	66	73	64	75	79	78	76	78	79	66
1 25.4	dv_1	—	—	—	—	23	29	44	36	54	37	40
	dv_2	—	—	—	—	41	40	52	46	60	45	53
	dv_3	—	—	—	—	48	44	59	47	64	40	44
1 27.4	dv_1	—	—	—	—	—	—	—	—	—	—	—
	dv_2	—	—	—	—	—	—	—	—	—	—	—
	dv_3	—	—	—	—	—	—	—	—	—	—	—
0 9.5	dv_1	—	—	—	—	—	35	89	157	87	85	72
	dv_2	—	—	—	—	—	28	76	156	90	88	69
	dv_3	—	—	—	—	—	63	127	194	112	104	139
0 10.5	dv_1	—	—	—	—	—	—	35	52	44	29	—
	dv_2	—	—	—	—	—	—	30	38	45	31	—
	dv_3	—	—	—	—	—	—	8	25	65	86	—
0 11.5	dv_1	31	22	14	14	26	35	38	41	42	45	46
	dv_2	34	21	16	13	22	28	29	33	34	46	45
	dv_3	31	24	22	27	44	61	64	61	60	62	62
1 15.5	dv_1	—	—	—	—	—	—	—	—	—	—	—
	dv_2	—	—	—	—	—	—	—	—	—	—	—
	dv_3	—	—	—	—	—	—	—	—	—	—	—
2 16.5	dv_1	28	33	37	32	—	—	—	—	—	—	—
	dv_2	30	34	41	36	—	—	—	—	—	—	—
	dv_3	39	43	50	44	—	—	—	—	—	—	—
1 17.5	dv_1	32	35	29	32	34	41	39	16	27	42	23
	dv_2	31	32	25	29	38	44	47	28	23	42	20
	dv_3	64	56	49	54	50	52	45	33	38	59	43
1 18.5	dv_1	—	—	—	—	—	47	53	75	69	71	63
	dv_2	—	—	—	—	—	54	64	82	78	78	62
	dv_3	—	—	—	—	—	66	72	87	82	84	71
1 20.5	dv_1	—	—	—	—	—	—	—	—	41	36	32
	dv_2	—	—	—	—	—	—	—	—	31	30	38
	dv_3	—	—	—	—	—	—	—	—	95	79	32
0 21.5	dv_1	—	—	—	—	—	—	—	—	—	—	44
	dv_2	—	—	—	—	—	—	—	—	—	—	45
	dv_3	—	—	—	—	—	—	—	—	—	—	57
1 23.5	dv_1	6	27	21	14	30	34	37	40	40	26	28
	dv_2	9	22	16	9	16	21	24	31	30	14	21
	dv_3	26	38	34	36	50	59	59	57	53	34	32
0 24.5	dv_1	33	32	34	28	25	34	41	38	36	44	54
	dv_2	30	24	26	19	35	27	32	30	29	39	49
	dv_3	40	42	42	36	43	46	53	52	45	51	58

noon	1 p. m.	2	3	4	5	6	7	8	9	10	11 p. m.	midn.
53	52	59	58	64	66	71	120	78	51	55	55	30
61	61	64	61	63	65	79	122	94	59	57	66	34
59	55	64	68	73	70	82	141	119	82	77	82	51
84	92	71	81	83	75	68	76	64	56	48	46	44
101	97	72	76	88	76	62	78	62	55	49	47	45
102	115	96	108	96	79	70	82	78	68	59	60	59
56	51	66	70	69	—	63	30	31	51	—	—	—
72	61	76	73	63	—	78	52	57	73	—	—	—
64	54	72	74	69	—	78	44	48	80	—	—	—
—	—	—	—	—	—	48	54	54	47	37	30	25
—	—	—	—	—	—	46	56	56	55	42	32	27
—	—	—	—	—	—	47	70	76	63	50	43	29
61	51	58	70	49	46	40	52	76	67	56	26	18
59	48	57	43	48	54	38	50	78	76	67	38	34
68	61	65	105	61	63	44	56	80	75	65	36	37
—	—	—	—	—	—	38	58	84	81	48	17	30
—	—	—	—	—	—	39	55	86	81	52	25	35
—	—	—	—	—	—	35	55	91	82	52	32	39
48	44	46	41	46	59	57	57	50	24	20	27	11
47	41	45	45	50	57	60	57	56	25	30	30	20
63	53	57	49	56	59	61	60	57	33	40	34	27
—	—	—	—	—	—	61	104	88	105	72	52	46
—	—	—	—	—	—	57	109	91	116	80	58	46
—	—	—	—	—	—	73	117	116	127	79	63	57
—	—	—	—	—	—	—	—	—	45	40	38	35
—	—	—	—	—	—	—	—	—	55	42	35	35
—	—	—	—	—	—	—	—	—	61	55	65	68
58	28	42	39	55	40	50	80	88	—	—	51	18
57	24	46	37	55	43	43	81	85	—	—	61	33
85	48	65	59	78	59	71	106	108	—	—	70	53
60	54	59	56	48	49	40	51	—	—	—	—	30
62	60	60	60	52	52	47	49	—	—	—	—	28
75	69	73	67	59	64	51	58	—	—	—	—	48
47	—	—	—	—	53	46	73	68	35	30	—	—
25	—	—	—	—	50	46	74	75	36	29	—	—
46	—	—	—	—	62	51	79	87	43	37	—	—
46	49	47	51	55	59	55	69	89	68	32	30	10
47	47	46	53	54	54	50	63	77	99	35	25	14
58	61	36	61	22	62	58	73	100	120	49	41	35
27	—	—	—	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—	—	—	—
35	—	—	—	—	—	—	—	—	—	—	—	—
52	55	60	60	64	56	53	53	46	49	37	32	37
47	58	60	60	65	62	57	51	47	53	40	34	34
57	61	61	58	59	55	53	56	52	50	41	40	45

1919		1 a. m.	2	3	4	5	6	7	8	9	10	11 a. m.
1 25.5	dv_1	30	25	32	38	41	38	44	47	41	38	31
	dv_2	24	24	31	30	37	31	36	45	41	47	36
	dv_3	38	36	44	56	53	66	58	57	54	49	40
0 26.5	dv_1	38	31	28	26	20	25	31	29	38	40	41
	dv_2	30	23	21	20	15	18	20	21	29	36	41
	dv_3	49	40	39	35	30	35	39	37	46	45	46
2 9.6	dv_1	48	42	26	22	27	30	49	46	49	45	41
	dv_2	47	40	25	33	31	29	50	49	50	38	39
	dv_3	76	68	62	65	58	60	74	64	60	57	51
1 10.6	dv_1	41	44	39	35	35	33	37	38	44	48	30
	dv_2	42	50	42	31	39	36	39	42	50	52	32
	dv_3	59	59	61	63	50	45	51	51	68	71	40
1 13.6	dv_1	22	33	—	24	30	27	32	26	33	26	36
	dv_2	38	40	—	31	34	29	32	30	35	26	41
	dv_3	32	34	—	32	39	43	39	33	40	33	36
1 15.6	dv_1	8	30	36	30	33	33	35	19	—	—	—
	dv_2	14	19	35	30	31	26	28	20	—	—	—
	dv_3	± 0	35	41	41	57	47	53	28	—	—	—
1 17.6	dv_1	40	40	29	26	26	30	33	31	34	35	45
	dv_2	48	47	32	37	29	38	43	42	42	42	55
	dv_3	47	42	29	36	35	39	40	39	37	40	50
1 18.6	dv_1	20	21	19	18	23	20	23	17	20	25	22
	dv_2	11	19	14	12	29	27	33	28	26	29	25
	dv_3	44	36	36	38	33	31	37	34	32	50	38
1 19.6	dr_1	35	26	18	14	16	11	38	38	41	43	39
	dv_2	34	29	19	17	12	10	42	36	47	38	42
	dv_3	40	26	30	22	19	20	43	68	51	57	49
2 1.7	dv_1	—	—	—	—	26	72	—	64	—	60	46
	dv_2	—	—	—	—	22	73	—	67	—	64	49
	dv_3	—	—	—	—	49	99	—	89	—	80	55
0 2.7	dv_1	—	—	—	—	36	45	37	41	—	51	48
	dv_2	—	—	—	—	32	49	55	49	—	57	52
	dv_3	—	—	—	—	17	53	59	58	—	61	60
0 3.7	dv_1	32	16	17	26	28	30	34	—	41	51	45
	dv_2	41	40	31	27	27	25	38	—	43	55	51
	dv_3	42	14	— 3	30	41	52	50	—	62	74	61
2 7.7	dv_1	—	—	—	—	—	—	—	—	—	61	—
	dv_2	—	—	—	—	—	—	—	—	—	59	—
	dv_3	—	—	—	—	—	—	—	—	—	59	—
0 8.7	dv_1	—	—	—	—	—	—	—	—	56	52	49
	dv_2	—	—	—	—	—	—	—	—	61	54	52
	dv_3	—	—	—	—	—	—	—	—	70	65	59
1 10.7	dv_1	—	—	—	—	—	—	—	—	—	—	30
	dv_2	—	—	—	—	—	—	—	—	—	—	29
	dv_3	—	—	—	—	—	—	—	—	—	—	38

noon	1 p. m.	2	3	4	5	6	7	8	9	10	11 p. m.	midn.
37	32	42	43	47	46	54	61	71	69	67	60	52
30	32	43	43	48	47	60	60	68	65	62	53	46
46	43	41	44	55	49	59	66	76	66	72	65	56
39	41	41	41	39	41	35	40	24	25	23	23	14
36	38	40	37	33	36	27	29	19	22	18	17	11
39	35	41	44	40	46	24	47	32	27	26	30	23
54	40	13	53	40	43	45	46	30	37	31	32	50
54	38	8	50	38	41	45	46	21	36	29	34	51
57	63	42	67	66	65	70	66	49	60	55	58	65
30	25	31	30	27	37	—	—	51	40	40	26	19
32	26	34	30	26	33	—	—	52	38	40	22	18
43	41	31	32	30	38	—	—	48	42	42	16	— 7
—	—	—	—	27	25	21	25	27	16	20	16	8
—	—	—	—	27	31	24	26	30	19	30	18	10
—	—	—	—	38	25	37	29	36	33	30	31	10
—	27	32	28	30	45	44	45	49	15	24	17	19
—	33	36	32	31	49	43	46	53	26	32	19	20
—	30	32	23	22	44	23	43	48	37	25	14	19
39	36	40	30	16	20	17	23	38	21	23	18	—
47	45	48	36	24	25	18	26	42	35	26	22	—
45	41	41	39	16	11	17	27	51	43	36	33	—
28	33	32	33	30	39	37	41	50	60	51	34	38
31	34	31	34	32	39	36	43	51	57	53	22	27
37	37	37	36	39	49	51	50	58	69	51	12	24
—	41	46	41	44	42	43	56	51	55	53	33	37
—	41	48	37	38	38	36	50	45	48	49	29	34
—	45	55	49	56	51	44	56	51	57	54	45	46
42	46	—	—	52	64	48	45	53	64	69	—	—
45	48	—	—	57	69	52	47	56	57	60	—	—
57	59	—	—	63	75	58	60	60	83	48	—	—
47	45	48	—	—	—	—	—	—	—	58	58	51
48	53	39	—	—	—	—	—	—	—	62	62	42
57	59	74	—	—	—	—	—	—	—	74	71	46
47	45	51	—	—	—	42	30	35	39	45	42	—
53	44	50	—	—	—	52	46	47	45	60	44	—
59	63	67	—	—	—	57	52	60	78	75	71	—
—	53	47	45	—	—	55	57	64	54	48	—	—
—	54	45	47	—	—	54	59	66	53	42	—	—
—	57	44	37	—	—	59	60	70	46	— 5	—	—
49	48	27	49	49	26	40	58	90	74	50	—	—
53	48	26	51	49	23	49	63	76	79	58	—	—
62	57	30	65	64	35	54	67	140	81	27	—	—
33	37	31	25	50	39	—	—	—	—	—	—	—
33	36	27	26	48	38	—	—	—	—	--	—	—
41	40	33	26	54	39	—	—	—	—	—	—	—

1919		1 a. m.	2	3	4	5	6	7	8	9	10	11 a. m.
0	dv_1	—	—	—	—	—	—	—	—	—	—	—
11.7	dv_2	—	—	—	—	—	—	—	—	—	—	—
	dv_3	—	—	—	—	—	—	—	—	—	—	—
2	dv_1	30	31	22	20	31	32	57	72	58	49	—
19.7	dv_2	24	26	21	18	28	24	53	72	59	48	—
	dv_3	39	36	37	20	32	28	59	71	64	48	—
2	dv_1	58	69	66	51	62	—	—	—	—	—	69
20.7	dv_2	50	62	44	34	52	—	—	—	—	—	74
	dv_3	86	87	101	61	73	—	—	—	—	—	76
1	dv_1	—	—	—	—	—	—	—	—	—	49	—
21.7	dv_2	—	—	—	—	—	—	—	—	—	49	—
	dv_3	—	—	—	—	—	—	—	—	—	74	—
1	dv_1	35	43	22	32	38	56	50	44	14	33	35
22.7	dv_2	26	38	14	35	28	54	45	32	23	20	27
	dv_3	34	10	21	32	30	69	54	43	38	32	31
1	dv_1	—	—	—	—	—	16	37	43	—	38	46
23.7	dv_2	—	—	—	—	—	12	35	41	—	38	46
	dv_3	—	—	—	—	—	10	36	40	—	37	51
1	dv_1	26	15	8	27	38	41	43	33	37	42	38
25.7	dv_2	23	12	10	29	41	45	47	36	23	47	40
	dv_3	29	25	25	35	44	42	66	44	59	42	45
1	dv_1	—	—	—	—	—	—	—	51	48	—	—
29.7	dv_2	—	—	—	—	—	—	—	55	51	—	—
	dv_3	—	—	—	—	—	—	—	56	61	—	—
1	dv_1	—	—	—	—	—	27	37	—	36	37	37
30.7	dv_2	—	—	—	—	—	27	36	—	30	39	39
	dv_3	—	—	—	—	—	33	44	—	65	55	53

direction of the tables. For the days where interpolated values occur the dates have been printed with half-heavy type. As an example can be given August 24th 1918 in tab. 9 where the interpolation referred to missing hour values for 2 and 3 o'clock p. m. The following values were thus inserted for 2 and 3 p. m. dv_1 24,24; dv_2 21,24; dv_3 18,20.

The Absolute Values of the Potential Gradient. — Mean Annual Values.

In tab. 10 are given mean annual values of the potential gradients as calculated for different character groups of observations.

To make a comparison the mean annual values were calculated, (1) from all hour values observed, (2) hour values of the days where an interpolation had

noon	1 p. m.	2	3	4	5	6	7	8	9	10	11 p. m.	midn.
—	—	—	—	—	—	54	53	—	42	42	33	33
—	—	—	—	—	—	50	53	—	55	42	34	39
—	—	—	—	—	—	56	59	—	55	42	24	— 29
33	48	36	61	47	47	46	62	68	80	—	81	60
33	41	28	69	75	85	70	95	92	93	—	83	57
30	51	43	65	65	91	65	97	99	106	—	107	86
49	46	49	52	—	—	40	—	—	—	—	—	—
52	49	61	49	—	—	49	—	—	—	—	—	—
59	54	61	59	—	—	47	—	—	—	—	—	—
—	—	46	40	40	30	38	40	52	—	49	49	24
—	—	42	38	36	26	35	30	50	—	49	49	28
—	—	60	38	49	42	30	49	68	—	62	44	45
36	38	38	34	—	—	—	46	—	50	52	45	45
26	35	37	33	—	—	—	47	—	59	64	44	56
26	32	36	35	—	—	—	32	—	54	57	3	42
46	46	40	27	29	21	33	—	—	26	43	—	—
44	51	41	27	28	23	34	—	—	26	50	—	—
44	38	36	31	23	28	37	—	—	24	43	—	—
—	—	37	30	37	30	40	53	56	56	28	18	14
—	—	32	24	30	27	38	50	55	54	31	17	11
—	—	46	24	38	32	39	49	61	57	40	22	20
—	36	46	—	24	37	56	57	60	—	—	—	—
—	39	48	—	27	37	60	57	65	—	—	—	—
—	45	52	—	37	41	63	71	70	—	—	—	—
33	30	37	29	34	40	25	22	—	22	22	—	30
32	27	37	30	31	38	25	22	—	22	19	—	30
42	37	43	34	37	46	30	27	—	20	17	—	21

been made. When looking at tab. 10 it is conspicuous how small the absolute values of the potential gradient in the respective horizontal layers are when compared to the mean annual values hitherto calculated from observations of the potential at different places in Europe. The mean annual value for Europe is 150 volts per metre or about three times the mean value of the gradient for the first metre above the ground at Upsala.

Most remarkable is the marked increase of the potential gradient with the height which is found in the observed data from Upsala. It is only for the character 0 that it shows a small decrease in dv_2, while for the more comprehensive data of observations of character 0—1 and character 0—1—2 the mean gradient value throughout increases with the height. The increase is more than three times as large in the case of the second interval 1—3 metres as in the

case of the first one 0—2 metres. As will be seen from another context (see p. 61) the variations of the gradient can in individual cases amount to extraordinary higher values than the one indicated by the mean values in tab. 10. And yet this is in the comparatively undisturbed group char. 0—1.

Tab. 10.

1. Non interpolated values.							2. Interpolated values.						
Character of day.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2	Number of observations.	Character of day.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2	Number of observations.
0	52.6	52.1	58.5	— 0.5	+ 6.4	283	0	50.8	48.4	57.5	— 2.4	+ 9.1	144
0—1	54.7	56.5	64.2	+ 1.8	+ 7.7	1 095	0—1	55.6	57.8	67.2	+ 2.2	+ 9.4	648
0—1—2	57.4	59.3	68.9	+ 1.9	+ 9.6	1 686	0—1—2	58.6	59.5	70.9	+ 0.9	+ 11.4	1 080

The Annual Variation of the Potential Gradient.

For a calculation of the annual variation from mean monthly values the observed results at hand are rather heterogeneous, which among other things is due to the fact that days, when occasional causes of disturbance influenced the gradients, have been left out of account or have been included only when the occasional disturbances were small (char. 2). As I believe chiefly thanks to the elimination of occasional disturbances, the mean monthly values of the potential gradient at Upsala give an annual curve that does not differ very much from the corresponding annual variation at some other places where there exists a greater amount of observation data.

The different mean monthly values for the whole period of observation with the fixed collector system are given in tab. 11.

Tab. 11. **Mean Monthly Values.**

Char.	J. (20)	F. (153)	M. (221)	A. (47)	M. (206)	J. (131)	J. (150)	A. (59)	S. (48)	O.	N. (44)	D. (21)
0—1												
dv_1	91.4	76.0	77.3	52.6	44.9	31.6	39.1	31.8	47.6	—	79.3	55.3
dv_2	105.8	80.2	79.2	59.2	43.8	33.5	39.9	32.9	45.2	—	74.7	61.7
dv_3	120.2	87.3	90.3	67.5	56.5	38.9	45.2	32.4	41.9	—	92.0	91.4
0—1—2	(68)	(235)	(302)	(96)	(214)	(155)	(206)	(92)	(102)	(51)	(101)	(89)
dv_1	90.4	89.2	77.2	58.4	44.6	32.8	42.8	33.2	44.5	64.5	73.5	47.6
dv_2	105.8	86.7	77.4	66.8	43.6	34.3	43.7	34.6	43.7	60.5	75.0	47.8
dv_3	115.4	99.4	93.3	81.0	56.3	42.4	49.7	29.2	42.1	52.1	75.8	77.7

In the same columns as the abbreviated names of the months, is given in parenthesis the number of the observations[1] used for the mean values in question. As the number varies considerably for different months a certain cautiousness is necessary when making a comparison between the respective mean monthly values.

One can not expect the same regularity for the gradients observed in the immediate vicinity of the ground as a little higher up in the atmosphere. The earth's surface is to be considered as an electrode, negatively charged by the ordinary positive field of the atmosphere. Solid particles that are whirled up from the ground, such as dust and snow, are therefore able to cause certain perturbations in the gradients observed close to the ground, which without being directly visible in the records will to a certain extent assert themselves in the mean values.

Also another circumstance will work in the same direction. Under certain meteorological conditions ionizated air will issue forth through the earth capillaries, while on other occasions these capillaries are clogged by water or snow. E. v. Schweidler[2] further points out that in the immediate vicinity of the ground the rapidly decreasing β-radiation of the earth's surface can play an important rôle for the variation of the field. Especially during periods of transition, when the ground is alternately covered with snow and frozen, or bare and thawed, one can expect certain variations and irregularities in the ionization and in the β-radiation. When in winter the ground has been covered with snow for some time the conditions become settled at the same time as a new and important factor comes in. There is almost continuously an evaporization from the surface of the snow. On certain occasions the evaporated water or ice vapour will condense in the layers at some distance above the snow,[3] and the air will there be filled with small particles of water or ice, which in their turn serve as ion-absorbers, and so light ions will become heavy. An originally homogeneous distribution of ions can by this means be converted into a discontinuous one, which in its turn can cause marked changes in the field variations.

An examination of the annual course of dv_1, dv_2 and dv_3, especially of the observations free from occasional disturbances, character 0—1, will to a certain extent favour the belief that circumstances of this kind have asserted themselves.

The annual course of dv_3 is the most regular one. The gradients for the lower layers, on the other hand, show certain irregularities in autumn and

[1] It must be pointed out that each "observation" consists of the mean value of 11 distinct recording points.

[2] E. v. Schweidler: Encyklopädie d. Math. Wiss. VI. I. 4. Leipzig 1918.

[3] It may be pointed out that the air over snow surfaces often is crowded with small suspended water particles as is stated by A. Wegener: Thermodynamik der Atmosphäre p. 294. Leipzig 1911.

especially at the transition to winter. In one particular case I want to refer to the gradients for November 20th 1918, when no doubt the newly fallen snow in some way or other has influenced the ionization, which explains the peculiar variation of the gradients in the lowest layers.

According to A. Daunderer[1] the potential gradient at Bad Aibling for 1—2 metres was markedly less than the one for 0—1 metre during the summer months, while the opposite was the case in winter. At Upsala, dv_2 for character 0—1 proves to be less than dv_1 only in September and November, and inconsiderably so in May. The differences between dv_2 and dv_1 are at Upsala during the summer months considerably smaller than those during the winter, which may be considered to support the reliability of A. Daunderer's results. That dv_2 should be greater than dv_1 as A. Daunderer had found for the winter months, was even in 1918,[2] i. e. 10 years after his observations were made, considered to belong to an observation result of such a kind that, when quoted, it was provided with a mark of exclamation.

According to tab. 11 there appears for dv_3 a very marked increase in comparison with dv_2 and dv_1 whether one calculates with undisturbed observations of the character 0—1 or includes such observations as to a certain extent were influenced by occasional causes of disturbance. For char. 0—1 only the mean values for August and September form an exception. The increase of the gradient is considerably larger in winter than in summer, which is connected with an increased tendency of molization and stagnation of the ions in winter.

Because of the different number of observations that are included in the respective mean monthly values of the potential gradient I have not considered it appropriate to carry the discussion of the annual variation, as indicated by the

Tab. 12.

Period char. 0—1	dv_1	dv_2	dv_3	d^2v_1	d^2v_2	Period char. 0—1—2	dv_1	dv_2	dv_3	d^2v_1	d^2v_2
Year (1095)	54.7	56.5	64.2	+ 1.8	+ 7.7	Year (1686)	57.4	59.3	68.9	+ 1.9	+ 9.6
Winter (415)	78.4	82.7	93.5	+ 4.3	+ 10.8	Winter (713)	76.7	79.2	95.0	+ 2.5	+ 15.8
Equinoxes (340)	48.2	48.1	56.6	— 0.1	+ 8.5	Equinoxes (520)	51.2	52.4	58.1	+ 1.2	+ 5.7
Summer (340)	34.4	35.7	40.1	+ 1.3	+ 4.4	Summer (453)	36.9	38.2	42.7	+ 1.3	+ 4.5

[1] Loc. cit. p. 37.

[2] Encyklopädie der Mathematischen Wissenschaften mit Einschluss ihrer Anwendungen Bd. VI. 1 B h. 4. Leipzig 1918.

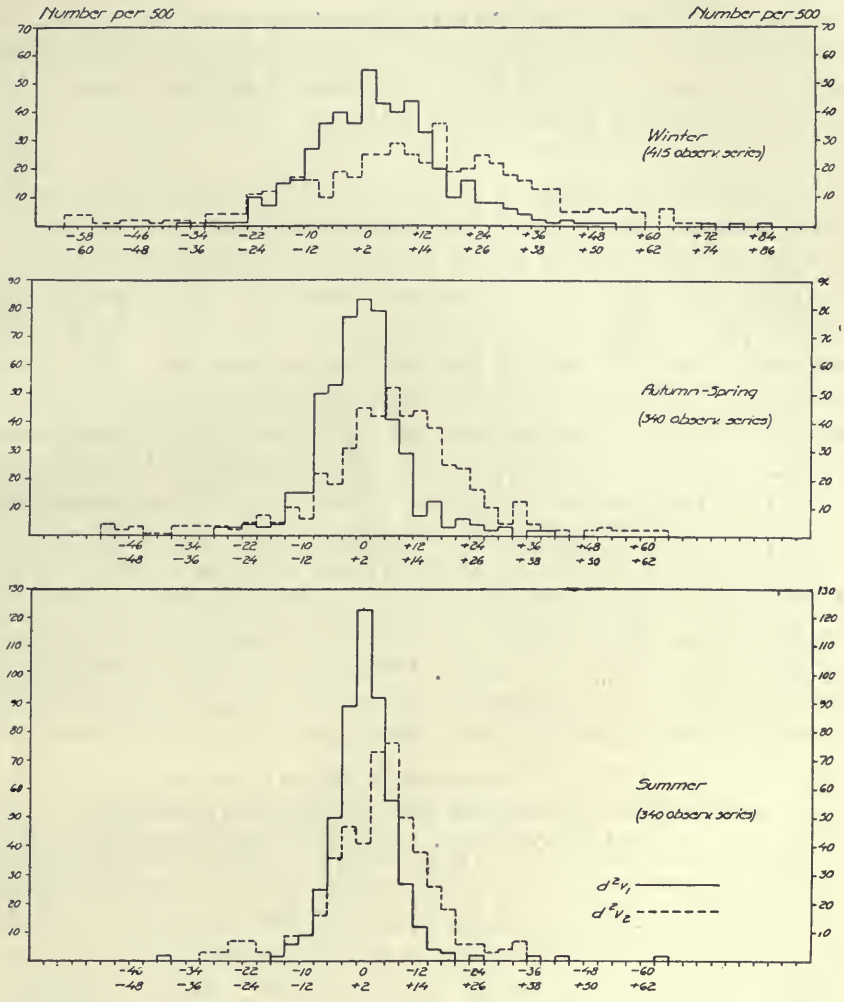

Fig. 16. Frequency curves per 500 showing second height differences of potential.

mean monthly values, any further, but only refer to the following classification of the material of observation: *Summer:* August 1918, June and July 1919; *Autumn and Spring:*[1] September, October, November 1918, April and May 1919; *Winter:* December 1918, January, February and March 1919.

The numerical results of the above classification into seasons are given in table 12. For the sake of comparison the mean annual values have also been

[1] For brevity this group is called equinoxes, although March ought to have been included in it, but not November and May. In the year of observation March had, however, a decided winter character which again could not be said of November.

Tab. 13. **Character of days 0—1.**

	Summer.			Spring and autumn.			Winter.			Year.		
	dv_1	dv_2	dv_3	dv_1	dv_2	dv_3	dv_1	dv_2	dv_3	dv_1	dv_2	dv_3
1 a. m.	30.3 (11)	31.9	36.5	31.4 (9)	28.3	41.0	48.9 (21)	48.9	56.4	40.1 (41)	39.8	47.7
2	29.5 (11)	31.7	31.1	32.6 (9)	28.8	40.3	46.2 (21)	43.4	54.5	38.7 (41)	37.1	45.1
3	23.6 (10)	24.0	29.5	30.4 (9)	24.2	42.7	41.1 (20)	39.3	47.8	34.1 (39)	31.9	41.9
4	24.8 (11)	26.3	33.6	29.9 (9)	23.6	43.4	42.6 (20)	39.3	51.3	34.8 (40)	32.2	44.7
5	29.5 (12)	29.4	35.2	32.0 (10)	31.3	45.2	46.5 (18)	42.4	56.8	37.8 (40)	35.7	47.4
6	29.9 (14)	30.0	38.2	38.2 (13)	34.5	50.1	54.2 (19)	51.2	65.5	42.3 (46)	40.0	52.8
7	35.1 (14)	36.8	45.0	44.8 (14)	39.7	55.4	64.9 (18)	65.4	73.6	49.7 (46)	48.9	59.3
8	34.9 (12)	36.8	44.7	52.4 (13)	50.2	57.9	69.8 (16)	74.8	80.9	54.1 (41)	55.9	63.0
9	36.5 (13)	38.2	50.8	48.4 (14)	46.4	59.1	76.6 (14)	85.2	88.4	54.2 (41)	57.0	66.5
10	40.1 (16)	41.6	49.6	45.4 (14)	46.5	60.8	85.6 (16)	96.9	107.4	57.5 (46)	62.3	73.0
11 a. m.	36.5 (16)	37.8	45.0	46.3 (15)	45.5	59.7	90.9 (16)	105.4	114.7	58.1 (47)	63.3	73.4
Noon	36.9 (12)	37.2	42.7	48.1 (15)	49.3	61.3	87.3 (15)	107.1	111.7	58.9 (42)	66.9	74.3
1 p. m.	36.9 (17)	37.0	41.3	58.3 (14)	60.2	65.1	95.7 (14)	113 8	119.4	61.8 (45)	68.1	73.0
2	39.6 (17)	39.4	44.1	62.6 (14)	64.2	67.1	104.1 (13)	117'5	128.3	66.0 (44)	70.4	76.3
3	34.2 (13)	34.9	35.5	63.9 (14)	63.3	72.6	99.4 (13)	101'1	118.9	65.8 (40)	66.3	75.6
4	34.6 (16)	34.3	37.8	63.7 (14)	61.0	62.3	99.1 (15)	100.6	122.1	65.1 (45)	64.6	66.7
5	33.7 (15)	33.8	35.5	58.3 (16)	60.7	62.6	107.2 (13)	110.0	131.5	64.3 (44)	66.1	73.7
6	36.7 (15)	38.1	38.9	56.7 (20)	57.5	59.7	94.5 (17)	97.5	116.4	63.3 (52)	65.0	72.2
7	40:3 (16)	42.0	43.9	66.9 (19)	68.4	75.1	108.6 (19)	111.8	129.4	73.7 (54)	75.9	85.0
8	47.1 (14)	48.9	56.9	67.6 (19)	69.7	75.7	102.6 (19)	104.8	119.8	74.9 (52)	76.9	86.7
9	37.5 (16)	40.8	48.1	59.5 (18)	67.4	67.6	97.7 (21)	99.0	111.7	67.7 (55)	71.8	78.8
10	38.6 (19)	42.4	42.7	47.9 (17)	53.4	49.4	83.7 (19)	88.0	92.4	57.1 (55)	61.5	61.9
11 p. m.	32.2 (16)	33.8	33.1	40.8 (15)	44.1	45.9	74.8 (17)	78.8	80.5	50.0 (48)	53.0	55.9
Midnight	27.9 (14)	29.3	23.4	31.5 (16)	35.6	37.6	60.7 (21)	61.9	64.7	42.5 (51)	44.7	44.8
Mean	34.4 (340)	35.7	40.1	48.2 (340)	48.1	56.6	78.4 (415)	82.7	93.5	54.7 (1095)	56.5	64.2

Tab. 14. **Character of days 0—1—2.**

1 a. m.	30.3 (16)	31.1	39.1	36.2 (19)	37.6	47.3	51.7 (36)	51.2	63.0	42.7 (71)	43.0	53.4
2	30.4 (16)	31.6	33.9	37.7 (19)	38.7	48.8	49.6 (36)	46.4	62.4	42.1 (71)	41.0	52.4
3	24.6 (15)	24.8	33.7	35.1 (19)	35.0	45.2	43.5 (34)	39.9	54.6	37.0 (68)	35.2	47.4
4	25.3 (16)	26.9	33.9	34.7 (19)	34.0	46.6	43.3 (32)	39.3	57.2	36.6 (67)	34.9	48.6
5	29.6 (18)	29.4	36.2	36.2 (18)	37.2	49.1	48.8 (30)	43.2	63.8	40.1 (66)	38.1	52.3
6	32.2 (19)	32.3	40.1	40.2 (22)	38.8	48.4	57.7 (30)	52.6	73.4	45.5 (71)	42.9	56.7
7	37.4 (16)	38.6	47.7	46.4 (22)	44.3	53.0	63.5 (31)	62.5	81.0	52.0 (69)	51.2	64.3
8	41.9 (17)	42.4	47.1	54.1 (20)	52.3	54.6	77.5 (28)	78.8	99.2	61.0 (65)	61.1	71.8
9	39.6 (17)	40.2	49.8	48.7 (18)	48.9	59.4	87.8 (24)	95.4	111.5	46.7 (59)	65.3	77.9
10	42.9 (20)	43.8	51.9	48.9 (20)	50.5	61.2	89.8 (29)	97.7	118.5	64.3 (69)	68.4	82.6
11 a. m.	39.9 (21)	41.0	46.6	51.3 (20)	52.2	62.6	88.4 (28)	98.4	112.2	62.9 (69)	67.5	77.9
Noon	40.3 (18)	41.0	43.5	56.0 (21)	53.3	62.1	84.4 (27)	97.5	107.4	63.3 (66)	68.0	75.6
1 p. m.	39.4 (23)	39.7	43.9	60.5 (21)	64.8	64.6	92.1 (24)	103.2	113.7	64.5 (68)	69.9	74.9
2	40.2 (23)	39.9	43.3	67.5 (21)	71.3	71.4	96.8 (25)	108.5	122.2	69.0 (69)	74.3	80.4
3	39.4 (18)	39.7	40.1	67.5 (22)	66.5	75.0	94.0 (25)	96.6	108.2	77.6 (65)	70.6	78.1
4	37.1 (20)	38.1	41.3	60.5 (22)	60.7	59.3	87.7 (25)	87.4	107.9	63.7 (67)	63.9	72.1
5	36.7 (19)	38.9	41.6	57.2 (22)	59.0	57.9	95.5 (25)	97.9	119.2	65.8 (66)	68.0	76.4
6	39.7 (21)	42.5	43.5	57.7 (26)	58.0	56.8	89.8 (28)	91.9	113 3	64.6 (75)	66.3	74.2
7	42.7 (20)	46.0	49.3	67.4 (23)	69.3	74.9	100.4 (32)	104.0	123.4	74.9 (75)	77.9	88.7
8	49.5 (19)	51.9	58.9	68.1 (25)	69.3	76.9	100.6 (32)	103.2	124.5	77.1 (76)	79.2	92.5
9	41.7 (21)	45.2	52.9	58.3 (26)	64.2	64.7	92.7 (35)	94.4	111.0	68.8 (82)	72.2	81.4
10	39.5 (24)	42.5	41.1	53.0 (26)	57.6	55.1	73.9 (33)	76.6	85.7	57.4 (83)	60.7	63.2
11 p. m.	35.2 (19)	36.7	37.6	47.2 (24)	51.9	53.6	72.9 (30)	76.6	82.3	54.6 (73)	58.1	61.3
Midnight	30.9 (17)	31.9	28.8	37.6 (25)	41.0	46.2	57.4 (34)	58.0	64.0	44.9 (76)	46.4	50.3
Mean	36.9 (453)	38.2	42.7	51.2 (520)	52.4	58.1	76.7 (713)	79.2	95.0	57.4 (1686)	59.3	68.9

inserted and for each period the number of the observations forming the arithmetical mean is given in parenthesis.

Up to 3 metres the mean potential gradient for undisturbed observations[1] (of the character 0—1) as a rule increases with the height, except for the equinoxes, when d^2v_1 only is $= -0.1$.

As could be expected, d^2v_2 is positive throughout all the seasons and this feature is especially pronounced during the winter. The influence of the weak disturbances can be traced in the mean values for the character 0—1—2. In winter they result in an increase of the gradient in the second interval, d^2v being 15.8, while the gradient of the first interval d^2v_1 decreases to 2.5, well-nigh half the mean value prevailing on undisturbed days. This proves the importance of the earth's surface as a charged electrode at whirling snow. In summer the disturbances do not cause any considerable changes in the mean values.

A graphical representation of the frequency per 500 observations of different individual values of d^2v_1 and d^2v_2 as calculated for the character 0—1 is given in fig. 16. According to this diagram the most frequent value of d^2v_1 lies throughout the three season groups between $+2$ and 0, while the most frequent value of d^2v_2 lies between $+8$ and $+6$ for summer and equinoxes and between $+17$ and $+15$ for winter. A comparison between the curves of d^2v_1 and d^2v_2 (in fig. 16) shows that the spreading is about twice as large in winter as in summer, while during the equinoxes it lies between these extremes. As high values of d^2v_2 as between $+48$ and $+66$ occur comparatively often during the winter.

Daily Variation of the Potential Gradients.

The daily variation firstly on undisturbed days of character 0—1 and secondly with inclusion of the slightly disturbed character 0—1—2, was calculated in the usual manner by forming mean values for the 24 hours of each day. A certain insecurity will necessarily be inherent in the result, due to the different number of observations that are included in the respective mean hourly values. The calculations have been carried on through the different seasons and the whole year. The result is given in tables 13, 14, where the figures in parenthesis show the number of hourly observations included in the means in question. A calculation was also made in which only the days marked with heavy type in table 9, were included and the gaps were filled by means of interpolation according to the method described on page 43. The result is shown graphically in fig. 17, 18.

With regard to its general characteristics, the daily variation at Upsala agrees with the results previously obtained at the same place[2] as well as elsewhere.

[1] When in this paper it is spoken of undisturbed observations it is meant such as are free from direct influence of accidental meteorological processes in the shape of precipitation, fog, and so on.

[2] H. Norinder, K. Sv. Vetenskapsakademiens Handl. *58*. 4. 21. 1917.

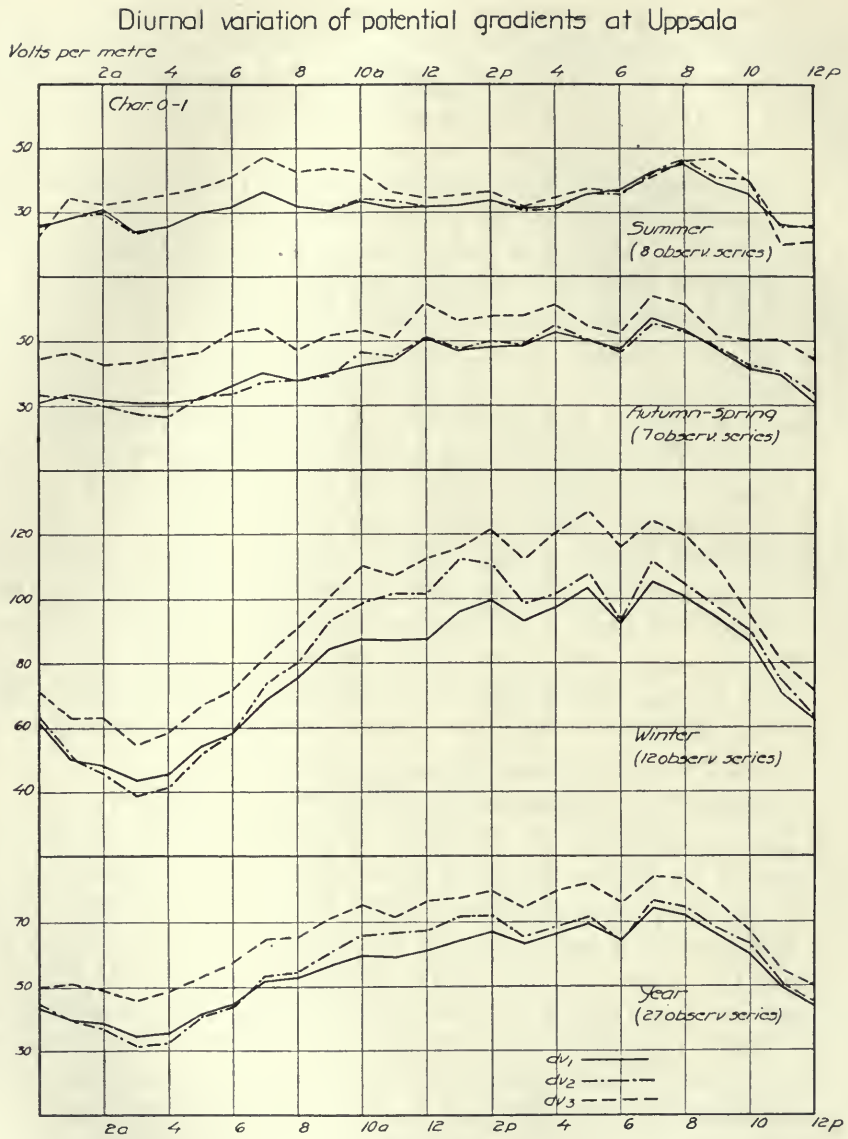

Fig. 17.

It is shown by tables 13, 14 and fig. 17, 18 that in summer there occur one morning and one evening maximum, a principal minimum about 3—4 a. m., a weaker one about noon or some hours after, thus a double-periodical variation. In winter, on the contrary, the daily variation is single-periodical with an evening

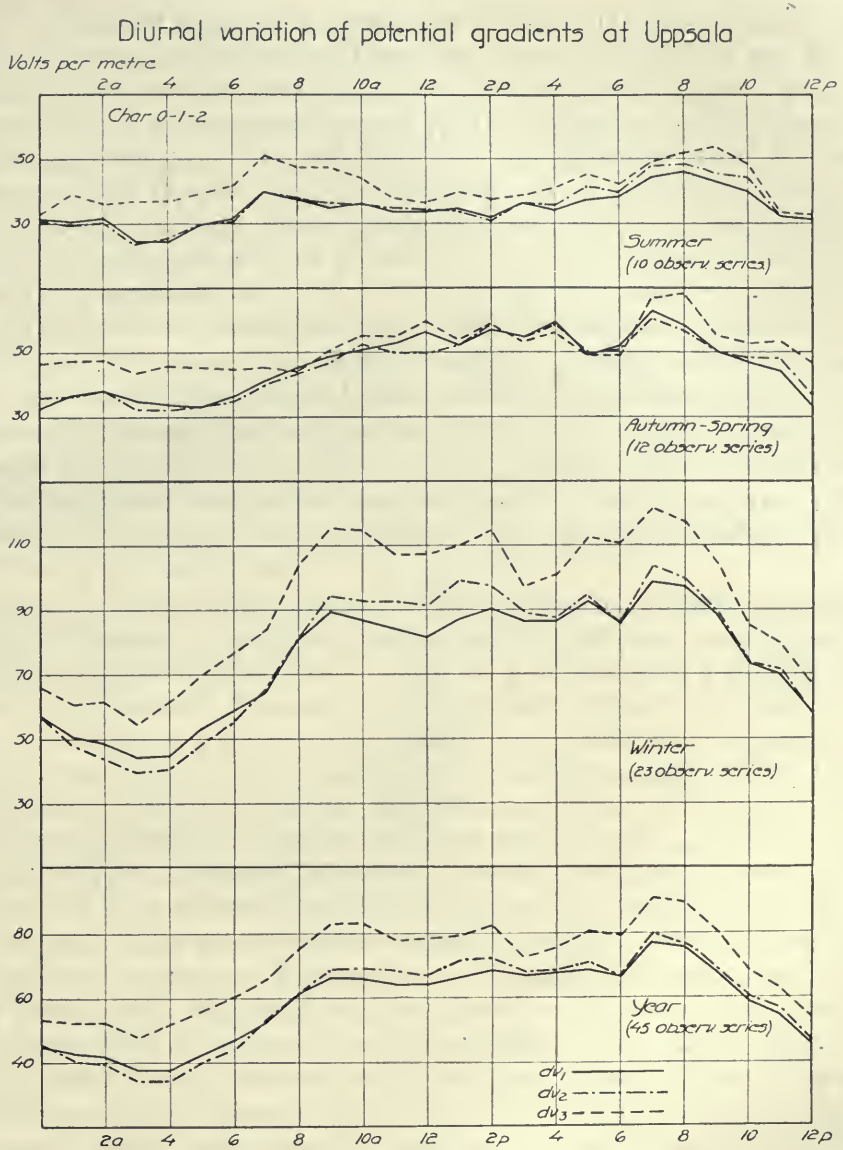

Fig. 18.

maximum and a marked early morning minimum. The daily variation during the equinoxes forms a transition stage between those of winter and summer.

If the gradients (for character 0—1) in the three intervals are compared during one season, dv_2 proves to diverge to a certain extent from dv_1 and dv_3. This

is especially the case in winter during some consecutive hours after 2 p. m. The difference $dv_2 - dv_1$ is for the said hours inconsiderable compared to $dv_3 - dv_2$. If we examine the variation during the other seasons, the same thing occurs, though less markedly. These irregularities may, as has already been ponited out, partly be caused by an amassing of ions in absorbing layers near the ground, where due to the general current of ions and the exterior field, positive charges have been amassed in excess in the vicinity of the ground.[1]

A fact that especially ought to be noticed is the inequality $dv_3 > dv_1 > dv_2$, in and about the principal minimum (3—4 a. m.) for character 0—1, both in winter and equinoxes. In the mean values for summer, on the contrary, it is only at 5 a. m. that there is a slight indication of the inequality, $dv_3 > dv_1 > dv_2$. In order to check this particular result I made in the autumn of 1920, by means of the movable collector system, some direct investigations of the gradient in the intervals 1.0—4.0 metres above the ground, at the time of the morning minimum 3.45 a. m. to 5 a. m. The observations were made on 3 different days with quiet, undisturbed weather conditions. The result is given in table 15.

Tab. 15.

Height in metres ..... Potential gradients in volts per metre.	0.0—1.0 dv_1	1.0—2.0 dv_2	2.0—3.0 dv_3	3.0—4.0 dv_4	Number of observations.
1920					
16.9, 27.9	55.9	51.3	61.5	88.1	6×3
6.10	79.2	100.1	142.1	76.9	3×3

In the six independent series on September 16th and 27th, dv_1 was in the individual cases $> dv_2$, and taken on an average the inequality, $dv_4 > dv_3 > dv_1 > dv_2$, is applicable. The observations in table 9 show that both in winter and in the equinoxes there are individual exceptions from the inequality, $dv_1 > dv_2$, and the series on October 6th showed such a diverging variation. The potential gradient was, however, on this occasion about twice as high as the normal one of the season, which possibly has some connection with the divergence of the variation with the height, compared to the series of September 16th and 27th.

It will be difficult to find any exhaustive explanation of the existence of the inequality, $dv_3 > dv_1 > dv_2$, at the time of the morning minimum, without a close analysis of the distribution of ions in the interval of observation. The inequality is found not to be applicable to the mean values for summer, which suggests that the distribution of the field may possibly to a certain extent be due to a secondary influence of molization, for instance sinking positively charged

[1] The out flow of positive ions in excess through capillaries from the earth may of course be of great importance in this connection. See note Ebert-Kurg cit. pag. 73.

layers of ions. Such layers are according to all probability formed chiefly in winter and equinoxes. The distribution, $dv_3 > dv_1 > dv_2$, at the time of the morning minimum can also be supposed to be connected with the weakening of the outer cosmic field that always occurs at the night side of the earth.[1]

The diurnal variation of the potential gradient calculated with inclusion in the mean values of slightly disturbed days of character 0—1—2 as well shows according to table 14 and fig. 18, no essential divergences from the corresponding variation of character 0—1.

The Potential Gradients and some Meteorological Elements.

Attempts have often been made to calculate the connection between the potential gradient and some other simultaneously observed meteorological elements. The potential gradients have been arranged in the ordinary manner according to magnitude groups of the meteorological elements whose connection was to be investigated, and then averages were taken of the different groups. The method suffers from certain weaknesses, but in some cases it has been considered to be the only possible one.

It will, however, in certain cases often be useless to attempt to establish any connection between the potential gradient and the meteorological elements. The latter depend mutually on one another in so complicated a manner that it is difficult to distinguish between direct and more indirect influences. There is one circumstance that renders this distinction more difficult. The meteorological elements are often observed according to much more inaccurate methods than those of atmospheric electricity. In cases when a connection has been calculated one has, nevertheless, sometimes had a comparatively limited material of observations at one's disposal and in such cases statistical methods will easily give a misleading result.

When, in spite of this, I will give below a juxtaposition of observations of the potential gradient and some of the meteorological elements observed at the Meteorological Institution, it ought to be interpreted rather as an attempt to check the observed data than to find out the connection between the meteorological elements and the observed potential gradients. An analysis of the relation between atmospheric electric and meteorological elements would in most cases require a special arrangement of the meteorological observations in the immediate vicinity of those of the atmospheric electricity and according to principles that are not usually followed at the work at a meteorological station.

For the juxtapositions here made have been used, on one side, only comparatively undisturbed observations[2] of character 0—1, and on the other the corresponding values of meteorological elements that are published in the Bulletin

[1] See also note p. 66.

[2] With the exception of the observations on November 20th noon—11 p. m.

of the Meteorological Institution.[1] The meteorological observations, with the exception of those of the wind, were made at the Instrument House of the Meteorological Institution, situated in the ENE direction about 75 metres from the locality of observation of the potential gradients. The wind observations were made on the roof of a house, situated in the Edirection at a distance of about 400 metres at a height above the ground of 25 metres.

According to what has been pointed out previously in this paper with regard to the influence of meteorological factors on the potential gradient a certain influence of the wind ought to be particularly expected, which both in calm weather and in strong wind is able to cause an abnormal ion distribution. At low wind velocity there will often occur a pronounced horizontal layering of the atmosphere near the ground characterized by small disturbance or turbulence, and on such occasions the conditions are favourable to the development of a strong ion absorption. In this case one may expect values of the potential gradient considerably diverging from the normal ones. In strong wind, on the contrary, dust and snow are whirled up from the earth's surface, which in this connection will represent a negatively charged electrode, and by these solid particles considerable free charges are sometimes produced. It is true that the observations of character 0—1 ought to be free from direct influence of the last-mentioned kind that could be noticed in the curves, but this does not prevent the lowest atmospheric layers from being mingled with electric charges arisen in the said manner, and this circumstance will of course lead to somewhat diverging gradient values.

A juxtaposition of hourly observations (for the whole year) of dv_1, dv_2 and dv_3 of character 0—1, and the corresponding average wind velocities is given in table 16.

Tab. 16.

Metres per sec.	Mean. Number.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2
0.0—0.9	0.8 (14)	77.4	82.1	97.6	+ 4.7	+ 15.5
0.0—1.9	1.6 (225)	56.1	58.7	67.6	+ 2.6	+ 8.9
2.0—2.9	2.5 (357)	52.8	55.6	61.8	+ 2.8	+ 6.2
3.0—3.9	3.4 (229)	54.2	55.4	63.2	+ 1.2	+ 7.8
4.0—4.9	4.3 (166)	57.8	58.2	66.2	+ 0.4	+ 8.0
5.0—5.9	5.3 (69)	59.4	61.2	69.7	+ 1.8	+ 8.5
6.0—6.9	6.3 (19)	62.7	59.1	63.8	— 3.6	+ 4.7
7.0—7.9	7.4 (13)	66.9	70.3	79.3	+ 3.4	+ 9.0

[1] F. Åkerblom, Bulletin mensuel de l'Observatoire Météorologique de l'Université d'Upsala, vol. L, LI. 1918, 1919.

As will be seen from the numbers of observations the frequency of the wind velocity is rather uneven; the greatest number of observations is found in the group 2.0—2.9. High mean values of dv_1, dv_2, and dv_3 correspond with some exceptions to high wind velocities, which partially depends on the fact that winter, autumn, and spring afford about 80 % of the number of observations in the three highest classes of wind velocities. If a comparison is made between dv_1, dv_2, and dv_3 of the groups 0.0—1.9 and 3.0—3.9, which are equivalent with regard to the number, it is found that the lower wind velocities cause higher potentials as well as higher values of d^2v_1 and d^2v_2. In this connection the calm weather periods will, as has already been pointed out, assert themselves with horizontal layering and great ion absorption. This is especially the case in the group 0.0—0.9, which contains high values both of dv_1, dv_2, and dv_3 and of d^2v_1 and d^2v_2. The group comprises, however, only a small number of observations. From an individual point of view they are very interesting. In the highest wind velocity groups there occur certain irregularities in the mean values of the potential gradients and their differences, which to a certain extent finds an explanation in the effect of whirling of solid particles.

In order to investigate more closely the connection between wind velocity and potential gradient a calculation was made, firstly of wind velocity groups and average potential gradients for the different seasons, table 17, and secondly of the corresponding values for city winds and country winds, tab. 18. I have namely presumed that the city, with its fireplaces will cause a large excess of heavy ions, which might considerably influence the result of the observations. As city winds were counted NNE, NE, ENE, E, ESE, SE and as country winds SSW, SW, WSW, W, WNW, NW.

According to table 17 the highest values of the potential gradients of winter are to be found in the lowest wind velocity classes, as well as the abnormally high values of d^2v_2. The explanation of this fact is, as already has been mentioned, partially an increase of the ion absorption, occuring in calm weather. The negative values of d^2v_1 that occur in the highest wind velocity classes during all the three seasons, appear particularly peculiar. In winter the groups from 4.0 to 6.9 metres per second are characterized by *low* or *negative* values of d^2v_1 and comparatively high values of d^2v_2, which probably is due to the friction between ice particles in the snow layer immediately above the ground. The groups with the lowest wind velocities in summer are characterized by low values of d^2v_1 and d^2v_2, contrary to those in winter.

As to city and country winds, table 18, the mean yearly value of dv_1, dv_2, and dv_3 of the former type are lower than those of the latter, if we look at the group comprising 0.0—3.9 metres per second.

An examination of the values for winter is very interesting, especially those

Tab. 17. **Wind velocity and**

Summer.							Equi-		
Group m/sec.	Mean. Number of observations.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2	Group m/sec.	Mean. Number of observations.	dv_1
0.0—0.9	0.9 (4)	29.0	30.5	29.3	+ 1.5	— 1.2	1.0—1.9	1.6 (40)	49.6
1.0—1.9	1.6 (89)	34.9	37.1	37.3	+ 2.2	+ 0.2	2.0—2.9	2.5 (101)	43.2
2.0—2.9	2.5 (125)	34.4	35.9	41.2	+ 1.5	+ 5.3	3.0—3.9	3.4 (85)	47.4
3.0—3.9	3.4 (61)	38.2	38.4	46.0	+ 0.2	+ 7.6	4.0—4.9	4.3 (71)	50.9
4.0—4.9	4.3 (38)	35.5	36.8	43.4	+ 1.3	+ 6.6	5.0—5.9	5.3 (20)	61.9
5.0—5.9	5.3 (17)	30.1	29.2	32.6	— 0.9	+ 3.4	6.0—6.9	6.3 (9)	72.9

Tab. 18. **Wind and potential gradient. SSW,**

Summer.							Equi-		
Group m/sec.	Mean. Number.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2	Group m/sec.	Mean. Number.	dv_1
1.0—1.9	1.6 (16)	32.7	33.4	41.6	+ 0.7	+ 8.2	1.0—1.9	1.5 (10)	37.6
2.0—2.9	2.5 (49)	29.5	32.1	33.4	+ 2.6	+ 1.3	2.0—2.9	2.6 (18)	39.3
3.0—3.9	3.4 (29)	35.7	37.1	43.2	+ 1.4	+ 6.1	3.0—3.9	3.6 (33)	50.8
4.0—4.9	4.3 (24)	34.2	36.5	42.2	+ 2.3	+ 5.7	4.0—4.9	4.3 (39)	50.5
5.0—5.9	5.3 (13)	30.6	29.2	32.2	— 1.4	+ 3.0	5.0—5.9	5.3 (16)	64.8
0.0—3.9	2.7 (94)	31.9	33.9	37.8	+ 2.0	+ 3.9	6.0—6.9	6.3 (9)	73.0
Year 0.0—3.9	2.7 (354)	60.5	62.8	70.0	+ 2.3	+ 7.2	0.0—3.9	2.9 (61)	45.3

NNE, NE, ENE, E, ESE,

Summer.							Equi-		
Group m/sec.	Mean. Number.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2	Group m/sec.	Mean. Number.	dv_1
1.0—1.9	1.6 (53)	37.8	40.1	36.0	+ 2.3	— 4.1	1.0—1.9	1.6 (25)	53.5
2.0—2.9	2.5 (47)	39.5	39.9	47.5	+ 0.4	+ 7.6	2.9—2.0	2.4 (45)	53.4
3.0—3.9	3.4 (20)	38.0	38.2	44.7	+ 0.2	+ 6.5	3.0—3.9	3.3 (17)	45.6
0.0—3.9	2.3 (122)	38.4	39.7	41.6	+ 1.3	+ 1.9	0.0—3.9	2.4 (87)	51.2
Year 0.0—3.9	2.2 (273)	51.8	54.1	62.0	+ 2.3	+ 7.9			

potential gradient. Char. o—1.

noxes.				Winter.						
dv_2	dv_3	d^2v_1	d^2v_2	Group m/sec.	Mean. Number of observations.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2
51.7	65.1	+ 2.1	+ 13.4	0.0—0.9	0.8 (10)	96.7	102.8	125.0	+ 6.1	+ 22.2
43.2	52.0	± 0.0	+ 8.8	1.0—1.9	1.3 (54)	115.2	119.8	142.3	+ 4.6	+ 22.5
47.5	54.8	+ 0.1	+ 5.3	2.0—2.9	2.5 (131)	77.7	83.9	89.0	+ 6.2	+ 5.1
50.9	52.2	± 0.0	+ 1.3	3.0—3.9	3.4 (83)	72.9	76.0	84.3	+ 3.1	+ 8.3
66.0	66.9	+ 4.1	+ 0.9	4.0—4.9	4.4 (57)	81.4	82.2	98.9	+ 0.8	+ 16.7
67.1	78.9	— 5.8	+ 11.8	5.0—5.9	5.3 (32)	73.4	75.2	91.2	+ 1.8	+ 16.0
				6.0—6.9	6.3 (7)	65.7	63.4	74.4	— 2.3	+ 11.0

SW, WSW, W, WNW, NW. Country winds.

noxes.				Winter.						
dv_2	dv_3	d^2v_1	d^2v_2	Group m/sec.	Mean. Number.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2
37.3	47.9	— 0.3	+ 10.6	0.0—0.9	0.7 (6)	98.8	96.7	116.8	— 2.1	+ 20.1
35.6	41.1	— 3.7	+ 5.5	1.0—1.9	1.6 (39)	82.7	87.5	96.5	+ 4.8	+ 9.0
49.9	56.6	— 0.9	+ 6.7	2.0—2.9	2.6 (92)	77.4	82.9	89.4	+ 5.5	+ 6.5
49.8	49.2	— 0.7	— 0.6	3.0—3.9	3.4 (62)	76.1	76.9	87.7	+ 0.8	+ 10.8
69.7	69.4	+ 4.9	— 0.3	4.0—4.9	4.4 (50)	85.0	84.1	105.1	— 0.9	+ 21.0
67.1	78.9	— 5.9	+ 11.8	5.0—5.9	5.4 (28)	76.5	77.4	94.7	+ 0.9	+ 17.3
43.6	50.6	— 1.7	+ 7.0	6.0—6.9	6.3 (7)	65.7	63.4	74.4	— 2.3	+ 11.0
				7.0—7.9	7.6 (6)	68.2	72.0	81.0	+ 3.8	+ 9.0
				0.0—3.9	2.6 (199)	78.7	82.4	91.1	+ 3.7	+ 8.7

SE. City winds.

noxes.				Winter.						
dv_2	dv_3	d^2v_1	d^2v_2	Group m/sec.	Mean. Number.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2
58.4	71.1	+ 4.9	+ 12.7	0.0—0.9	0.9 (4)	93.5	112.0	137.3	+ 18.5	+ 25.3
55.5	63.3	+ 2.1	+ 7.8	1.0—1.9	1.5 (32)	62.5	62.4	89.1	— 0.1	+ 26.7
47.6	57.6	+ 2.0	+ 10.0	2.0—2.9	2.4 (22)	93.1	99.0	103.5	+ 5.9	+ 4.5
54.8	64.4	+ 3.6	+ 9.6	3.0—3.9	3.7 (6)	83.8	90.3	93.2	+ 6.5	+ 2.9
				0.0—3.9	2.0 (64)	76.9	80.7	97.4	+ 3.8	+ 16.7

of d^2v_1 and d^2v_2. In the group city winds there exist in the lowest wind velocity classes abnormally high values of d^2v_2, which probably are caused partially by disturbance from the city. But the country winds as well present high values of d^2v_1 which, however, are more pervading throughout the different wind velocity groups than is the case with the corresponding values for city winds.

Some remarks may be made upon the above calculations of the variation of potential gradients with the wind directions. Especially at higher wind velocities the instrument hut could indirectly disturb the potential gradients in the first instance at wind directions coincident with the wire directions between the posts. At easterly winds eddy motions would set in at the end-wall of the hut nearest to the collectors, at west winds a stagnation would set in at the same end-wall, which in this case was situated to the windward. The vertical components of the wind force were in such cases probably very small in the proximity of the collectors. None the less I found it necessary to control the above-mentioned disturbing effect of the instrument hut by a special grouping of the observations, char. 0—1. The groups in question comprised the following cases of wind directions:

1) The end-wall nearest the collectors sheltered from the winds.

2) The same end-wall to the windward.

3), 4) Winds parallel to the same end-wall.

The observations were also grouped with regard to two different wind force classes. The result is given in tab. 19.

Tab. 19.

Wind direction.	Wind velocity.		Potential gradients.			Mean values.		Number of observations.
	Group.	Mean.	dv_1	dv_2	dv_3	d^2v_1	d^2v_2	
E, ESE 1)	$\leqq$ 3.0 m/sec.	2.1	56.3	57.3	62.0	+ 1.0	+ 4.7	71
E, ESE	$\geqq$ 3.1 »	3.5	60.1	59.0	65.8	+ 1.1	+ 6.8	10
W, WNW 2) ...	$\leqq$ 3.0 »	2.0	55.0	51.6	63.4	— 3.4	+ 11.8	39
W, WNW	$\geqq$ 3.1 »	5.0	56.9	56.3	67.0	— 0.6	+ 10.7	82
N, NNE 3).....	$\leqq$ 3.0 »	2.3	47.3	48.2	55.6	+ 0.9	+ 7.4	38
N, NNE	$\geqq$ 3.1 »	4.0	39.2	38.2	50.0	— 1.0	+ 11.8	30
S, SSW 4)	$\leqq$ 3.0 »	2.0	33.2	36.6	41.8	+ 3.4	+ 5.2	37
S, SSW	$\geqq$ 3.1 »	3.9	54.7	57.9	59.3	+ 3.2	+ 1.4	58

As can be seen there is a marked difference between the values of d^2v_1 and d^2v_2 of the groups W, WNW, and N, NNE compared to the other groups. Any

indirect disturbing effect on the ion distribution and the potential gradients caused by the instrument hut in the shape of eddy motions or stagnations are not to be found by the calculations given in the tab. 19.

Two other meteorological elements, namely air temperature and cloudiness were also put together with the potential gradient. Table 20 shows the result of the calculation concerning the temperature of the atmosphere.

In summer the gradients, especially dv_1, increase with the temperature, which possibly is due partially to an increased issue of ions from the earth capillaries, a process that according to investigations by Ebert and Kurz[1] would result in an issue of positive ions in excess. In this connection the turbulence and the vertical ventilation of the air nearest to the ground is of a certain importance, as well as the similardaily variation of temperature and potential gradient. In winter the gradient increases with the temperature, which is clear from tab. 20 if we compare for instance two groups that are so equivalent with regard to the number of observations as —6.1 to — 9.0 and ± 0.0 to + 2.9. The increase of the potential in mild winter weather is perhaps connected with a transport of ionized air with the winds of the south- and west-quadrant from districts with bare ground.

In connection with the classification of the potential registrations (page 34) it may be of interest to make a comparison between the cloudiness observed at the hours 6 a. m., 8 a. m., 10 a. m., noon, 2 p. m., 5 p. m., 7 p. m., and 9 p. m. and the simultaneous values of the potential gradient of character 0—1. A juxtaposition of this kind is given in table 21, where the number of the observations in the group in question is given in parenthesis.

The three middle groups 1—3 to 7—9 in table 21 show comparatively irregular values without any pronounced tendency. It is interesting to compare the extremes, cloudiness 0 and 10. The values of the potentials are everywhere lower for cloudiness 10 than for 0, which is the more noticeable as it is the case with the gradients of all the three height intervals. To a certain extent the explanation of this fact is certainly to be found in an increased tendency of horizontal layering and accordingly absorption of ions accompanying cloudiness 0, which tendency is reduced in case of a quite overcast sky. The higher gradient values at clear sky may perhaps also be explained as due to the absence of the screening from the outer field, which of course takes place to a certain extent when the sky is entirely clouded.

Some Remarks Concerning Individual Observations.

During the progress of the investigation I have made on certain occasions some notes on the meteorological conditions, which it may be convenient to

[1] H. Ebert—K. Kurz, Phys.Zeitschr. II. 389. 1910.

Tab. 20.

Summer.					Equinoxes.					Winter.				
Temp.	Mean. Number.	dv_1	dv_2	dv_3	Temp.	Mean. Number.	dv_1	dv_2	dv_3	Temp.	Mean. Number.	dv_1	dv_2	dv_3
+ 9.0 – + 11.9	+ 10.9 (38)	24.7	25.5	29.9	— 0.1 – — 3.0	— 1.3 (10)	36.9	40 7	62.4	— 15.0 – — 12.1	— 12.6 (18)	63.3	65.7	81.3
+ 12.0 – + 14.9	+ 13.5 (69)	34.0	34.8	42.4	± 0.0 – + 2.9	+ 1.5 (32)	56.2	64.1	67.8	— 12.0 – — 9.1	— 10.7 (56)	65.7	71.5	81.8
+ 15.0 – + 17.9	+ 16.6 (73)	36.9	38.3	40.9	+ 3.0 – + 5.9	+ 4.5 (39)	42.2	45.4	48.0	— 9.0 – — 6.1	— 7.5 (62)	72.4	76.4	90.2
+ 18.0 – + 20.9	+ 19.3 (62)	38.0	38.5	45.4	+ 6.0 – + 8.9	+ 7.4 (69)	48.8	48.2	53.1	— 6.0 – — 3.1	— 4.1 (83)	72.1	75.2	80.7
+ 21.0 – + 23.9	+ 22.3 (50)	40.9	42.6	45.2	+ 9.0 – + 11.9	+ 10.4 (61)	49.6	49.5	55.6	— 3.0 – — 0.1	— 1.5 (107)	81.6	84.7	94.7
+ 24.0 – + 26.9	+ 25.2 (23)	39.0	39.0	42.5	+ 12.0 – + 14.9	+ 13.4 (38)	56.6	55.0	62.9	± 0.0 – + 2.9	— 1.4 (59)	90.4	92.4	105.3
					+ 15.0 – + 17.9	+ 16.8 (35)	47.2	45.2	61.3	+ 3.0 – + 5.9	+ 4.3 (26)	79.3	85.3	101.2
					+ 18.0 – + 20.9	+ 19.4 (41)	48.4	46.7	52.5					

Tab. 21.

Group of cloudiness.	Summer.			Equinoxes.			Winter.		
	dv_1	dv_2	dv_3	dv_1	dv_2	dv_3	dv_1	dv_2	dv_3
0	41.3 (40)	43.4	48.0	58.4 (79)	59.6	64.3	99.5 (60)	104.3	121.8
1—2—3	39.0 (37)	38.6	46.5	54.5 (28)	56.6	61.1	78.8 (18)	82.7	91.1
4—5—6	38.3 (31)	39.3	41.9	51.1 (20)	49.5	58.7	96.7 (18)	109.7	130.2
7—8—9	44.9 (27)	46.7	53.0	54.6 (11)	59.0	65.9	82.5 (26)	91.0	104.8
10	35.0 (21)	37.6	40.4	54.5 (38)	55.4	57.0	77.9 (104)	80.2	101.7

compare with the individual observations of the potential gradient as given in table 9 page 44.

1918 Aug. 24 1 a. m.—6 a. m. very clear and good visibility, strong wind. The values of d^2v_1 and d^2v_2 are comparatively low.

Aug. 26. Early in the morning clear weather, good visibility and low values of d^2v_1 and d^2v_2.

Aug. 30. In the morning were observed stratus clouds, sometimes touching the tops of the steeples of the Cathedral, 119.8 metres high. At 9 a. m. these clouds dispersed. At 11 a. m. and 1 p. m. the values of d^2v_2 were exceptionally high for the time of the day, which perhaps may be ascribed to rest charges from the dispersed stratus clouds, remaining in the lower atmospheric layers.

Sept. 7. Very undisturbed with sometimes pronounced negative values of d^2v_2.

Nov. 20. Undisturbed weather conditions with very clear air.

The gradient values are very irregular and dv_2 is at 1 p. m. and 2 p. m. even negative. The d^2v_1 and d^2v_2 values as well show great variations. Snow had fallen the previous evening and the ground was covered with a layer of snow. No driving snow was observed.

Nov. 24. Somewhat hazy air nearest to the ground, both dv_1, dv_2, and dv_3 and d^2v_1 and d^2v_2 show rather irregular variation.

Dec. 12. Mild weather with comparatively strong S or SW wind; the ground becomes bare, especially on ploughed fields in the vicinity of the locality of observation. The value of d^2v_1 is found sometimes to be negative, while d^2v_2 without any exception reaches positive values. This variation with the height of the gradients is possibly connected with an opening and uncovering of the earth capillaries by the thawy weather.

1919 Jan. 23. After 6 p. m. there are undisturbed conditions.

Jan. 29. Before noon hazy air was observed here and there near the ground. Fog appeared at noon; at 2 p. m. and 5 p. m. it was noticed in an extended layer in the plane surface round the collectors from the ground and up to a few decimetres above the collector at 2 metres height The collector at 3 metres was during these hours situated in fogless air. At the same hours d^2v_2 was found to be low in comparison with d^2v_1 and at 2 p. m. it was even negative. The reason for this is probably that the fog-layer at its upper surface absorbs positive ions in excess. The variation of the gradients in the morning may possibly have the same cause.

1919 Febr. 8—9. The air is extraordinarily clear and on the 9th before noon d^2v_1 is positive, d^2v_2 negative, while in the evening the conditions were the reverse. No corresponding pronounced change in any meteorological element can be noticed.

Febr. 10. Especially in the evening there is clear air and undisturbed weather conditions. This is also the case on Febr. 15th in the evening and on the 16th. The latter day at 10 p. m. the air is very raw due to a fall of temperature.

Probably on the 16th the air is divided into horizontal layers and accordingly there is a strong ion absorption causing some irregularities in the potential gradients. In the values of d^2v_2 there occurs a pronounced change at 10 p. m.

Febr 27. Good visibility during the day and in the evening but hazy layers of air here and there nearest the ground. Sometimes the values of d^2v_1 and especially of d^2v_2 are high.

March 4. Very clear air and undisturbed conditions. Between 4 a. m. and 8 a. m. a SW wind is blowing, which at 11 a. m. changes to W at the same time as it increases in force. In the evening the wind decreases and changes to SW again. The relative humidity sinks 10 a. m. —11 a. m. 23 % from 60 % at 10 a. m. In the morning d^2v_1 is distinctly negative, while in the middle of the day there occur values about zero. Pronounced negative values of d^2v_2 occur from noon to 3 p. m. while both in the morning and in the evening there are some high positive values. These changes in the gradients are probably connected with certain pronounced changes in the ionization of the air of which the changes in the meteorological conditions were manifestations.

March 6. High values occur of dv_1, dv_2, and dv_3 probably due to ion absorption in hazy air, especially 4—6 p. m.

March 13 and 14. There is clear air and undisturbed weather conditions.

March 25. The peculiar variation of the gradients that is noticed from 1 a. m. and later is a typical one caused by driving snow. Whirling snow has, as can be seen, the power of causing a very considerable change in the gradients in the nearest metres above the ground. The values obtained on this day were not included in any calculations.

Juni 13. Between 6 p. m. and midnight the clouds have a tendency of becoming lower and lower, dv_1, dv_2, and dv_3 sinks to very low values and at midnight a few drops of rain are observed.

The observations in the table include upon the whole only values of the potential gradients that are free from influence of precipitation, dense fog, driving

snow, dust, and so on. On days of character 2 values are included at some of the hours of observation that were slightly influenced by some of the meteorological phenomena just mentioned.

It would not be worth while to enter into detail on the variation of the potential gradients during fog, snow etc. on the basis of the hourly observations contained in character 2. A more reliable result might possibly be obtained if the complete observations collected during precipitation etc. between Aug. 1st 1918 and July 31st 1919 were treated together. This will possibly be done on another occasion; the subject of this paper being a study of the potential gradients under more normal conditions.

For a further discussion in individual cases of the material given in the table 9, could be used the detailed meteorological observations published in the annual bulletins of the Meteorological Institution.[1]

As I have already pointed out the great variation of the potential gradients and especially of their differences with the height wich occurs in the lowest atmospheric layers requires certain qualifications of the simultaneous meteorological observations, if they are to be used for a closer investigation into the interaction between the meteorological factors and the potential gradients in the layers in question. With regard to the temperature of the atmosphere for instance, it is not so important to know the temperature at a certain point, as to observe the variation of the temperature with the height and the tendency to horizontal stratification in the lowest atmospheric layers. With regard to the wind velocity it is hardly of any importance to know the average wind velocity at some more or less disturbed point of observation but rather to learn to know the wind structure in the lowest layers, where the potential gradients are observed.

Observation with the Movable Collector System.

With the stationary collector system results of the height variation of the potential gradient were obtained, which differed from what was the general opinion to be the normal in the atmospheric layers close to the ground. On an average the potential gradients were found to *increase* with the height, and in certain cases *this increase was very pronounced.* It therefore seemed to be advisable to check and extend the obtained result by additional investigations in which the interval of observation might preferably be extended to greater heights.

For these observations was used the movable collector system that has already been described on page 12. A horizontal diagram of the arrangements is given in fig. 19.

In fig. 19 the posts of the stationary collector system are represented by A and B, the instrument hut by $\mathcal{J}$ and the 9.5 metres high posts of the movable

[1] Se pag. 68.

collector system by A_1 and B_1. The observations with the latter were thus made in a vertical plane parallel to the stationary collector system $A—B$ so that its observation points (C_1) were located directly opposite to those of the fixed collector system (C) at a distance of 1.3 metre. The collectors of the movable system were carried by insulated wires that could be moved pararellelly to the ground in a vertical plane from 0 to 9.5 metres height. As to the charging qualities of the movable collectors I refer to the tests described on page 22 and

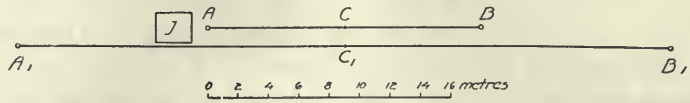

Fig. 19. Horizontal sketch of observation planes for stationary and movable collector systems.

following. They showed that the potential differences to earth of the middle points of the collector wires could be observed with sufficient accuracy by means of the movable collector system, when their heights were varied from 0 to 9.5 metres.

Method of Observation.

An observation of potential gradients in the vertical plane between the high posts could conveniently be made in the following manner. With the stationary collector system the potential difference to earth of one of the fixed heights, for instance 3 metres, was observed. At the same time the potential difference to earth was observed with a collector movable to different heights between 0 and 9.5 metres.

A change in the atmospheric potential during the time of observation, observed with the stationary collector, should through calculation be introduced on the simultaneous values obtained with the movable collector. This method requires, however, that a change in the potential of the stationary collector is followed by a proportional change for the movable one. Unfortunately the variations of the potential with the height is not so simple as that. In order to demonstrate this I give in fig. 20, 21 simultaneous registrations of the atmospheric potential with the stationary collector at 3 metres height and the two collectors of the movable system fixed at 7.0 and 7.43 metres respectively. The points marked with ⊙ are simultaneous 5 minutes averages for the different collector points. If the variation of the potential with the time at 7 metres is calculated from the one at 3 metres fairly great divergences from the potential actually observed at 7 metres are often found. The reason is that the space between is filled with free electric charges. As those charges could vary considerably with the height, it was considered appropriate to use two movable collectors with a relatively

short distance between them for the observations of the potential gradient in the movable system.

The observations were therefore made in the following manner. For measuring the potential differences were employed the three Benndorf quadrant electrographs that had previously been used in the stationary collector system. One of them was connected to one of the stationary collector wires, the two others to the two collectors of the movable system. At the observations the collector carriages on each post were by means of the block and falls and the graduated guides placed so that the lower of the movable collectors was located at a height of 1.0 metre and the upper one at 1.43 metre. The division lines on the guides had been made by levelling from the ground right below the movable collectors. When the collectors had been arranged in the said manner the three electrographs were made to record simultaneously during 4 minutes, so that 3 undisturbed registration points were obtained. Then the carriages were moved so that the lower collector was at 2.0 metres and the upper at 2.43 metres, and all the 3 instruments were again made to record. The same process was repeated until the lower of the movable collectors was at 9 metres and the upper at 9.43 metres. Series of observations were equally often made in the opposite direction, i. e. the observations were commenced with the lower movable collector at 9.0 metres and the higher at 9.43 metres and then the carriages were successively lowered. After the removal I waited with starting the registration of the electrograph long enough to permit the systems to assume the potential of the atmosphere. From Oct. 17th the lower movable collector was placed at 0.5 metre as well and further at 1.0 metre, 2.0 metres, and so on.

By this means a successive registration of potential differences was obtained for one fixed collector point and for two movable ones at 1.0 (0.5), 2.0, 3.0—9.0 metres and as a rule it took me about one hour to make such a series of observations. Three distinct simultaneous registation points were thus obtained for each height interval, with the movable system and with the stationary one.

The working up of the observations was made in the following manner. The ordinate values for the electrograph in question were read off with a millimetre scale and averages were taken for the 3 minute-period. The averages obtained were multiplied with the calibration constant of the respective electrograph, and a series of potential differences to earth was thus obtained for 0.5—0.93 metre, 1.0—1.43 metres, 2.0—2.43 metres etc. to 9.0—9.43 metres besides the simultaneous value at, for instance, 3 metres in the stationary collector system. The observations in the stationary collector system had in view to control that the potential was not subjected to too large changes during the time of observation and to test the charging qualities of the collectors. If, as sometimes happened, there occurred a divergence between the potential difference of the movable collector

when at 3 metres and the simultaneously recorded potential difference in the stationary system at the same height, then an accidental insulation defect could be suspected, generally in the shape of cobweb threads during the warm season. On such occasions the systems were subjected to a careful supervision before any more observations were made. The rate of charging was often tested at observations with the movable system as well as with the stationary one. If

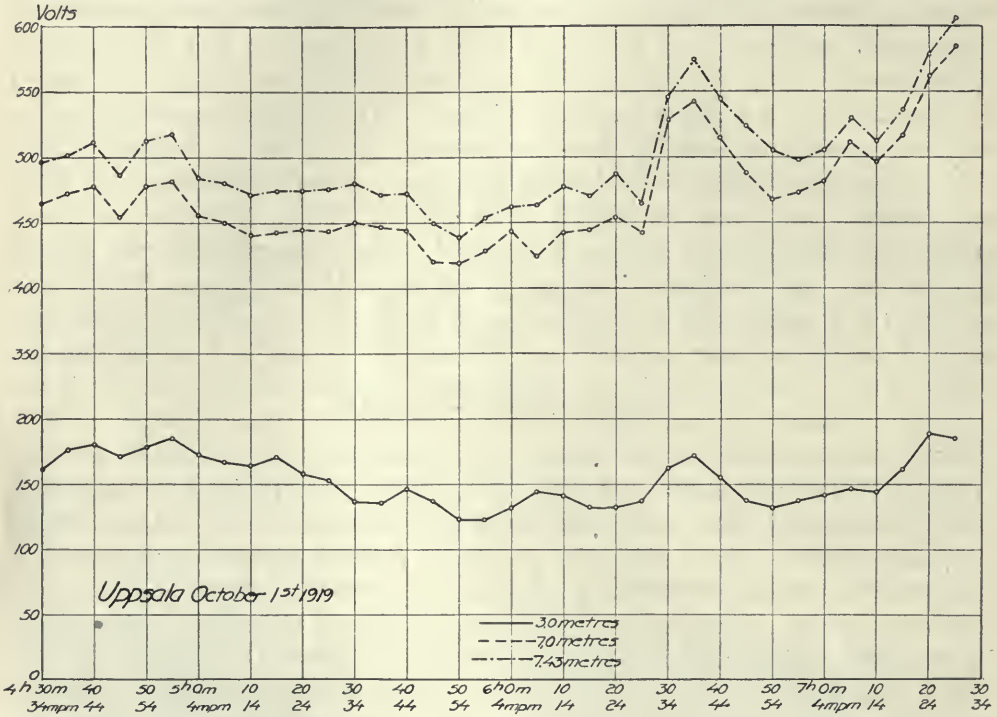

Fig. 20. Simultaneous observations of potential at three different heights.

the final potential was not reached in less than 1 minute or in exceptional cases 1.5 minute, when the collector was not covered, an insulation defect could be suspected. In order to examine those defects more closely the collector of the wire in question was wrapped up in several turns of paper with a layer of tinfoil farthest in and then the system (electrograph + collector wire) was charged with a positively charged glass pipe to about its normal potential difference from earth. By observing the system during a few minutes it was thus easily found out, whether there was any insulation defect or not.

From the simultaneous voltages at 0.5, 0.93, 1.0, 1.43 metre etc. the differences 0.93—0.5 metre, 1.43—1.0 metre etc. were taken and tabulated. In order to obtain more even numbers these potential differences (for 43 cm. distance)

were, however, transformed into differences for 50 cm. A difference $0.93—0.5$ metre deduced into 50 cm. was marked down as 0.75 metre height above the ground, i e. a point nearly coincident with the average height above the ground of the movable collector wires. In the beginning of the observations up to Oct. 10th 1918 observations with the lower movable collector were not made lower than 1 metre above the ground. The potential differences thus obtained were

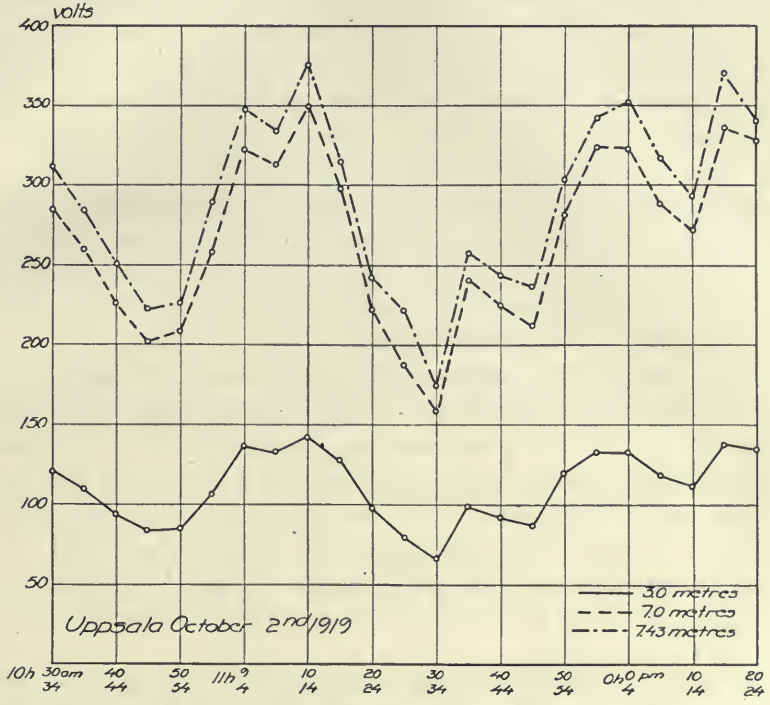

Fig. 21. Simultaneous observations of potential at three different heights.

cut in two and tabulated as 0.75 metre. When the corresponding observations were begun with the lower collector at 0.5 metre this value was recorded without any calculation as prevailing for the middle point of its height, i. e. 0.25 metre.

Attempts were made to correct the respective potential differences obtained with the movable system for variations in the potential gradient during the time of observation, with the help of the simultaneous registrations of the stationary one. Because of the fact pointed out on p. 79 those corrections did not give any results that could be considered as reliable. The method would have required a simultaneous registration at, for instance, three fixed collector points at 3.6 and 9 metres at the same time as the observations with the movable system. With the instrumental resources at my disposal I was therefore compelled to

make the observations of the gradient in the interval 0—9.5 metres with two adjacent practically identical collector systems, where errors occurring through the variation of the potential during the time of observation were compensated by the comparatively short distance between the collectors and by the great number of observations.

In order to obtain a measure of the variation of the potential in the stationary system during the time of observation the average potential difference of the system during the whole time was calculated together with the percentage difference between this average and the average obtained for each group of 3 minutes when the movable collector system was placed with its lower collector at 0.5, 1.0, 2.0 etc. to 9.0 metres. These differences, marked with + when higher than the average and with — when lower, were also tabulated.

The results of the observations thus obtained are shown in table 22. In the top line are given dates and hours of observation. Then follow the observed gradient values transformed into volts per 0.5 metre. As an illustrating example may be chosen Jan. 22nd 1920 3.0—3.50 p. m. In the column 0.25 metres we find 56, which thus indicates the gradient observed between the earth's surface and 0.5 metre above the ground. In the column 3.25 metres is found the value 80, which is the observed gradient for 3.43—3.0 metres deduced into volts per 0.5 metre and so on.

In the second line from the bottom in column 2.0 metres we read 258, which is the average potential difference for 2 metres during the time of observation. The values + 16 and — 19 at the bottom show the highest positive or negative per cent differences between the average 258 and any one of the ten 3-minute averages, when the movable system was placed with its lower collector at 0.5, 1.0 etc. to 9.0 metres.

The values of the potential gradient *(dv)* are naturally influenced by the electrostatic disturbance of the hut (see p. 20). Precise values of the gradients in the movable system can be obtained by multiplying the values up to 3 metres by the factor 1.02, 4 metres by the factor 1.01, 5 metres by the factor 1.005. The values from 6 metres and higher on are probably uninfluenced.

There are some gaps in the tables. In such cases, especially for the higher deflection values, the registrations of one of the electrographs have sometimes been indistinct or else disturbances have occurred towards the end of a registration, so that it had to be discontinued. In summer-time such disturbances would especially occur as whirling dust and in winter as whirling snow. In winter-time pronounced disturbances were sometimes caused by smoke from the adjacent hospital or from a blacksmith's shop situated within the premises of the Observatory. Several series where half the observations had already been made, had to be discontinued for this reason. On certain occasions direct meteorolo-

gical disturbances as well have asserted themselves, about which see further below. The dates of such observations were put in parenthesis in the table. After the respective date there is in the table another figure, see page 90. In a few cases of failing registration the gap was filled by interpolation in the vertical direction, which in the table is indicated by the letter i. before the figure in question.

The observations with the movable collector system given in the table 22 without any parenthesis round the date were made on days, when there was comparatively fine weather, and as to character the potential gradients may be considered to correspond to character 0—1 of the stationary collector system, see page 34.

Variation of Potential Gradient with Height 0—9 metres, Seasonal, Yearly and Diurnal Means.

The data in the table 22 are too unevenly distributed with regard to different months to permit a calculation of the yearly variation from the mean monthly values. In table 23 the observations are classified according to seasons in the same manner as previously the observations in the fixed system.

Averages for the different seasons were taken:

1) of all observations included in the table 22 with the exception of the disturbed values on April 25th 1920,
2) of all observations except some days especially indicated in the table 23,
3) of observations where the series have no gaps in the whole interval of observation.

In fig. 22 and 23 the averages of 1) and 3) are also shown graphically.

An examination of the mean values for the different heights fully confirms the results obtained with the stationary collector system. As a rule the potential gradient increases with the height in the lowest layers of the air.

In summer-time the increase is fairly even throughout the interval of observation with the exception of the values deduced from observations of the potential in the lowest height intervals. Tne potential gradient (dv) has at 0.25 metre about the same value as at 1.25 metre while at 0.75 metre the value is a little lower. Considering the facts pointed out on page 73 this remarkable variation in the layer close to the ground might find an explanation in the greater issue of positive ions caused by the outflow through the earth capillaries so much the more as the majority of the observations included in the averages were made in the daytime when the earth capillaries are more open.

The variation of dv with the height is least pronounced during the equinoxes,

Tab. 22. Individual Values of Potential Gradient at 0,25—9,25

Date.	21.8	26.8	26.8	31.8	31.8	2.9	3.9—4.9	5.9	6.9	6.9	11.9	28.9
Height m.	10—11,45 a.	11 a.—1 p.	7—8 p.	8—9 p.	9—10 p.	9—10 a.	12 p.—1 a.	5—6 p.	7,56—8.50 p.	11,0—11,45 p.	9—10 a.	3—4 p.
0,25	—	—	—	—	—	—	—	—	—	—	—	—
0,75	16	28	23	15	19	26	36	25	26	11	24	36
1,25	24	35	25	19	17	29	44	25	30	24	34	39
2,25	25	33	28	21	19	29	44	27	30	28	35	42
3,25	24	35	30	22	23	34	53	32	35	27	40	40
4,25	27	32	33	24	19	37	56	33	32	41	39	42
5,25	28	42	31	22	21	40	61	35	31	42	39	34
6,25	28	46	39	25	21	37	69	32	41	43	36	40
7,25	28	44	34	21	22	30	82	26	27	44	30	36
8,25	27	35	19	—	19	26	85	32	19	40	27	30
9,25	—	—	—	—	22	23	—	28	22	23	—	41
3,0 m.	144	209	158	118	114	183	247	182	163	—	205	233
%	−12, +10	−14, +13	−13, +9	−12, +9	−11, +11	−21, +19	−13, +14	−10, +13	+11, −10	—	+14, −13	+11, −7

Date.	20.10 5	21.10 3	21.10 2	22.10 2	23.10 6	23.10 6	23.10 6	24.10 3	24.10 6	25.10 5	25.10 6	30.10 7
Height m.	5,24—7 p.	8,30—9,30 a.	1,20—2,16 p.	9,0—10,0 a.	9,0—10,0 a.	0,0—1,0 p.	4,30—5,30 p.	0,38—1,30 p.	4,27—5,20 p.	9,30—10,20 a.	2,0—3,0 p.	5,0—6,0 p
0,25	22	19	37	20	29	34	32	12	34	39	90	83
0,75	26	26	42	23	28	43	28	4	42	40	99	87
1,25	19	22	40	26	24	47	43	8	45	42	87	77
2,25	20	17	43	26	27	43	42	20	37	47	79	81
3,25	30	21	43	27	22	45	35	34	29	48	97	73
4,25	23	29	43	22	24	38	40	24	28	48	113	99
5,25	22	24	40	30	27	35	36	24	22	44	79	86
6,25	13	24	33	14	26	38	35	12	8	72	94	66
7,25	19	26	33	28	i 23	45	31	17	7	64	63	49
8,25	11	i 23	49	21	20	—	26	22	—	56	59	49
9,25	19	20	55	14	24	—	26	17	—	47	49	8
3,0 m.	139	—	205	152	169	237	224	98	222	273	432	467
%	+19, −21	—	+12, −9	+9, −4	+11, −11	+10, −12	+4, −7	+7, −5	+10, −11	+14, −8	+56, −41	+13, −12

Date.	22.1 4	22.1 7	23.1 3	(6.2) 6	7.2 5	8.2 2	12.2 5	13.2 3	13.2 6	15.2 6	20.3 5	21.3 5
Height m.	8,45—9,40 a.	3,0—3,50 p.	9,43—10,40 a.	3,30—5,7 p.	3,10—4,10 p.	3,0—4,0 p.	3,14—3,56 p.	9,0—10,0 a.	3,5—4,18 p.	3,15—4,0 p.	9,0—10,0 a.	2,0—3,0 p.
0,25	48	56	73	41	—	81	65	41	—	47	44	—
0,75	60	61	71	50	56	97	83	75	53	59	99	27
1,25	73	67	67	51	50	106	108	86	77	56	95	17
2,25	80	66	80	68	68	106	84	84	75	42	88	32
3,25	90	80	65	65	53	91	74	72	85	60	97	35
4,25	141	80	58	173	49	69	91	92	65	48	100	34
5,25	123	92	58	53	51	76	74	90	89	53	85	36
6,25	90	97	70	210	49	109	74	78	56	59	88	31
7,25	166	115	62	30	36	188	—	57	36	63	75	42
8,25	169	108	47	38	17	72	—	—	—	31	40	44
9,25	154	92	59	26	22	256	—	—	—	32	46	60
2,0 m.	213	258	222	3 m. 259	283	443	402	340	340	277	340	172
%	+33, −11	+16, −19	+29, −19	+10, −12	+18, −7	+22, −27	+41, −30	+21, −11	+8, −9	+8, −9	+12, −11	+42, −25

Date.	2.5 6	2.5	(6,5) 5	14 6 6	15.6 4	16.6	17.6	23.6	28.6	28.6	29.6	29.6
Height m.	9,45—10,45 a.	5,0—6,0 p.	8,0—9,0 a.	2,15—3,15 p.	8,0—9,0 p.	0,45—1,45 p.	11,45 a.-0,30 p.	10,0—10,47 a.	2,45—3,30 p.	7,45—8,30 p.	11,45 a.-0,45 p.	0,45—1,30 p.
0,25	34	33	12	34	37	37	32	16	14	36	24	27
0,75	36	35	13	30	15	21	20	7	13	36	27	30
1,25	43	36	11	34	23	13	25	13	13	45	25	22
2,25	34	34	19	31	35	17	17	14	17	46	29	31
3,25	35	33	25	29	28	22	19	13	25	43	35	35
4,25	36	35	12	30	40	24	24	16	19	46	39	28
5,25	32	37	16	36	43	32	18	15	20	39	39	28
6,25	11	29	33	46	50	22	25	14	20	34	43	28
7,25	10	29	38	42	52	29	39	14	8	36	43	46
8,25	13	29	52	60	54	21	35	10	20	36	50	85
9,25	37	31	63	53	51	47	40	8	29	38	60	48
3,0 m.	170	189	203	1,0 m. 68	76	49	37	20	34	67	58	54
%	+21, −14	+10, −11	+36, −17	+59, −28	+28, −34	+31, −35	+51, −51	+50, −10	+35, −44	+19, −33	+31, −31	+37, −17

Date.	13.7	29.7	29.7	29.7	29.7	2.8	2.8	2.8	3.8	3.8	3.8	4.8
Height m.	2,0—2,45 p.	11,0—11,45 a.	11,45 a.-0,45 p.	0,45—1,30 p.	1,30—2,15 p.	10,30-11,15 a.	11,15—12,0 a.	0,15—1,0 p.	10,0—11,0 a.	11,0—11,45 a.	11,45 a.-0,45 p.	2,0—2,45 p.
0,25	16	18	14	18	12	15	15	13	28	19	21	24
0,75	20	12	14	14	15	13	10	14	30	13	18	23
1,25	20	12	13	16	13	11	13	6	27	20	23	23
2,25	21	15	15	30	16	12	14	13	31	21	24	30
3,25	25	20	16	23	16	12	19	12	32	25	17	33
4,25	22	15	19	25	22	18	17	21	36	31	26	46
5,25	24	19	14	23	24	22	19	25	35	29	25	33
6,25	25	18	12	22	24	22	20	22	31	29	33	33
7,25	27	19	16	22	24	28	24	17	37	26	36	30
8,25	28	12	19	24	28	27	24	17	39	24	64	26
9,25	34	18	21	24	22	32	27	23	40	30	60	27
1,0 m.	38	26	26	37	32	26	30	29	42	30	38	41
%	+34, −42	+46, −19	+23, −27	+41, −22	+25, −38	+54, −62	+17, −23	+35, −31	+26, −21	+27, −33	+66, −53	+21, −17

metres above Ground in Volts per 0,5 Metre. Upsala 1919—1920.

28.9	29.9	29.9	29.9	3.10	3.10	4.10 3	4.10	11.10 8	12.10 8	16.10 6	17.10 7	18.10
6,30—7,18 p.	19,0—9,44 a.	0,40—1,30 p.	6,27—7 p.	5,45—6,34 p.	8,27—9.10 p.	4,30—5,9 p.	7,45—8,50 p.	9,30—10,30 p.	11,30 a.-0,30p.	11,30 a.-0,23p.	11,5—11,49 p.	6,41—7,40 p.
—	—	—	—	—	—	—	—	—	—	—	35	35
17	34	24	25	12	24	22	29	19	21	22	29	36
i 28	51	44	32	i 16	24	23	37	7	27	34	23	27
38	51	41	31	19	23	27	35	12	22	30	22	24
35	56	44	31	42	13	35	35	14	17	30	22	27
35	50	52	32	41	21	44	34	9	15	28	24	33
42	50	42	35	44	23	30	31	11	16	34	37	35
48	47	42	28	50	30	37	31	11	17	28	15	30
41	83	47	31	63	34	40	34	28	16	28	12	23
32	85	40	27	61	47	43	33	16	—	28	6	38
38	88	32	33	55	41	52	26	17	—	20	6	37
215 +23, —13	254 +17, —13	178 +13, —19	152 +7, —18	53 +4, —4	140 +47, —33	131 +21, —21	175 +15, —10	124 +28, —27	149 +21, —14	162 +10, —10	172 +27, —23	202 +9, —17

31.10 6	1.11 i 6	1.11 5	2.11 3	8.11 7	11.11 7	11.11 7	14.11 4	16.11 8	18.11 6	27.12 2	21.1 4	21.1 3
5,0—6,0 p.	0,0—0,45 p.	4,30—5,30 p.	10,0—10,45 a.	0,30—1,30 a.	0,0—1,0 p.	10,0—11,0 p.	1,0—2,0 p.	0,40—1,30 p.	2,0—3,0 p.	2,0—3,0 p.	2,30—3,15 p.	5,58—6,45 p.
30	27	23	63	21	25	11	41	—	36	61	53	68
38	28	20	72	14	26	16	53	37	36	106	84	67
44	26	16	77	14	26	26	53	40	36	110	102	69
48	27	22	80	20	32	35	47	43	36	121	92	123
51	31	26	73	21	26	41	46	45	35	145	120	105
63	26	20	115	19	13	41	39	42	35	121	149	111
85	26	20	83	20	31	51	39	35	32	i 120	160	20
62	19	29	84	20	37	62	41	36	31	120	200	76
—	19	27	62	26	55	47	52	45	32	169	86	28
—	17	19	41	26	45	46	66	41	—	—	102	42
—	16	12	—	26	44	50	64	—	—	—	61	—
341 +52, —30	166 +13, —10	183 +41, —24	405 +20, —27	80 +2, —5	— —	182 +28, —16	260 +23, —15	215 +7, —17	200 +55, —19	2 m. 272 +9, —10	197 +32, —28	266 +38, —16

21.3 4	22.3 5	22.3 6	23.3 6	23.3 4	25.3 6	3.4 4	4.4	23.4 5	23.4 4	24.4 5	(25.4) 3	28.4 6
5,0—6,0 p.	8,15—9,15 a.	5,25—6,5 p.	8,10—9,8 a.	5,44—6,50 p.	10,0—11,0 a.	6,30—7,30 p.	2,30—3,30 p.	2 - 3 p.	6,0—7,0 p.	0,30—1,30 p.	11,0—12,0 a.	6,0—7,0 p.
45	43	38	23	55	66	—	41	14	21	29	38	19
28	63	40	53	52	72	57	35	9	17	22	35	20
38	66	42	49	52	61	69	40	11	20	22	34	28
34	56	42	44	47	57	80	39	14	21	25	34	16
32	62	56	53	47	71	80	32	10	22	33	37	16
33	55	54	67	52	78	89	26	19	26	i 34	26	23
40	62	53	53	52	57	103	33	13	27	34	15	29
36	55	48	53	52	62	106	21	16	28	23	— 1	23
43	57	47	50	54	53	i 88	30	22	30	18	— 15	18
38	57	42	47	49	99	70	39	17	34	19	— 16	24
28	55	38	43	48	54	45	40	12	27	19	— 16	16
184 +18, —17	234 +16, —10	215 +24, —12	190 +23, —24	238 +26, —19	293 +23, —27	369 +18, —12	229 +24, —20	88 +3, —2	120 +9, —10	170 +29, —11	151 +51, —54	161 +7, —9

29.6	30.6	2.7	2.7	2.7	2.7	2.7	7.7	12.7	13.7	13.7	13.7	13.7
5,45—6,30 p.	10,45-11,30 a.	10,45-11,30 a.	11,30 a.-0,30 p.	2,0—3,0 p.	3,0—3,45 p.	5,45—6,45 p.	10,30-11,30 a.	1,40—2,25 p.	10,30-11,30 a.	11,30 a.-0,15 p.	0,30—1,15 p.	1,15—2,0 p.
27	25	28	25	24	22	16	27	9	16	18	15	17
30	27	28	30	23	34	24	22	15	17	21	15	23
28	31	31	29	31	48	24	32	15	17	22	19	22
35	33	32	31	30	36	28	17	22	24	24	29	23
30	31	33	31	37	41	34	11	25	22	23	33	27
33	27	30	31	32	36	32	23	18	21	28	29	28
53	31	30	37	37	36	29	20	28	20	22	23	30
35	37	36	32	33	32	27	16	23	21	22	30	28
34	64	41	35	32	33	14	17	23	37	27	28	25
51	46	37	43	72	34	23	21	29	25	22	27	30
52	47	47	46	42	45	32	3	23	24	25	25	28
59 +22, —22	45 +20, —18	48 +12, —8	45 +7, —16	42 +21, —17	44 +9, —7	33 +15, —15	27 +111, —81	21 +29, —48	37 +32, —14	37 +19, —16	37 +24, —19	40 +15, —15

4.8	5.8	5.8	9.8	9.8	9.8	10.8	10.8	13.8	13.8	13.8	13.8	13.8
6,45—7,30 p.	11,30 a.-0,15 p.	0,15—1,15 p.	10,45-11,45 a.	11,45 a.-0,30 p.	0,30—1,30 p.	10,45-11,30 a.	11,45 a.-0,30 p.	10,45-11,30 a.	11,30 a.-0,15 p.	0,15—1,0 p.	1,15—2,15 p.	2,15—3,0 p.
35	31	23	25	27	28	23	24	21	22	20	24	22
24	23	13	20	17	24	23	18	17	14	12	21	17
25	20	15	25	18	24	20	37	11	12	17	20	21
35	25	24	24	19	25	31	32	17	10	23	24	25
39	27	19	25	19	29	38	37	15	18	23	23	24
52	35	24	25	30	32	33	38	11	17	17	18	27
44	33	26	43	35	30	37	33	6	18	20	20	30
63	37	31	35	35	33	36	36	12	21	15	17	30
64	33	39	30	32	33	42	30	13	36	21	21	25
65	55	43	56	25	33	44	27	15	30	26	18	26
60	48	42	44	48	44	50	45	25	31	27	24	20
65 +13, —13	46 +11, —13	41 +29, —15	50 +18, —16	44 +48, —16	44 +11, —16	43 +23, —21	41 +20, —17	30 +33, —50	35 +29, —29	29 +28, —21	33 +33, —21	— +10, —18

Tab. 23.

Average Variation of Potential Gradient with Height. 1918—1919. Upsala Volts per 0.5 metre.

	Metres.											Days omitted.	Series.
	0.25	0.75	1.25	2.25	3.25	4.25	5.25	6.25	7.25	8.25	9.25		
Summer.	22.6	20.2	22.0	24.7	25.9	27.4	28.4	28.9	30.6	33.2	32.7		1)
	47	52	52	52	52	52	52	52	52	51	48		
	22.6	20.2	21.8	24.6	25.8	27.5	28.4	28.6	30.7	34.6	35.7		3)
	(47)	(1920)									(47)		
Equinoxes.	32.2	31.1	33.6	34.5	36.5	38.0	37.9	36.2	36.2	35.9	32.9	1920 $^{25}/_{4}$	1)
	29	48	48	48	48	48	48	48	47	44	40		
	33.8	31.8	34.7	35.6	37.2	39.2	39.0	37.1	37.0	36.5	32.8	1919 $^{20}/_{10}$, $^{21}/_{10}$,	2)
	26	45	45	45	45	45	45	45	44	41	37	1920 $^{25}/_{4}$, $^{6}/_{5}$	
	30.9	31.4	32.2	31.6	33.6	34.0	34.2	31.2	31.1	32.0	30.5		3)
	(25)										(25)		
Winter.	52.7	65.1	68.7	70.9	74.2	81.9	71.3	81.6	72.9	61.2	67.1		1)
	18	21	21	21	21	21	21	21	20	17	16		
	51.6	63.6	67.6	69.2	73.8	77.8	72.0	73.4	68.8	62.1	56.6	1920 $^{6}/_{2}$, $^{8}/_{2}$	2)
	16	19	19	19	19	19	19	19	18	15	14		
	49.2	61.8	64.0	63.7	69.4	76.2	74.0	75.8	72.6	69.1	59.2		3)
	(12)										(12)		
Year.	31.3	32.3	34.7	36.6	38.5	41.1	39.6	40.9	39.9	38.8	39.3	1920 $^{25}/_{4}$	1)
	94	121	121	121	121	121	121	121	119	112	104		
	31.1	31.8	34.4	36.2	38.1	41.9	39.6	39.4	39.0	38.8	37.4	1919 $^{20}/_{10}$, $^{21}/_{10}$,	2)
	89	116	116	116	116	116	116	116	114	107	99	1920 $^{25}/_{4}$, $^{6}/_{5}$, $^{6}/_{2}$, $^{8}/_{2}$	
	28.9	29.4	30.9	32.3	34.4	36.4	36.6	36.2	36.8	38.7	37.5		3)
	84										(84)		

where, however, the greater number of observations in fig. 22 gives a variation that agrees with the one in winter with a turning point at 4—5 metres. This type of variation is most pronounced in winter. It seems to be quite natural that it should occur least pronouncedly in the summer averages. If the increase of dv with the height is interpreted as chiefly due to an excess of heavy negative ions the increased vertical ventilation in the lowest atmospheric layers generally

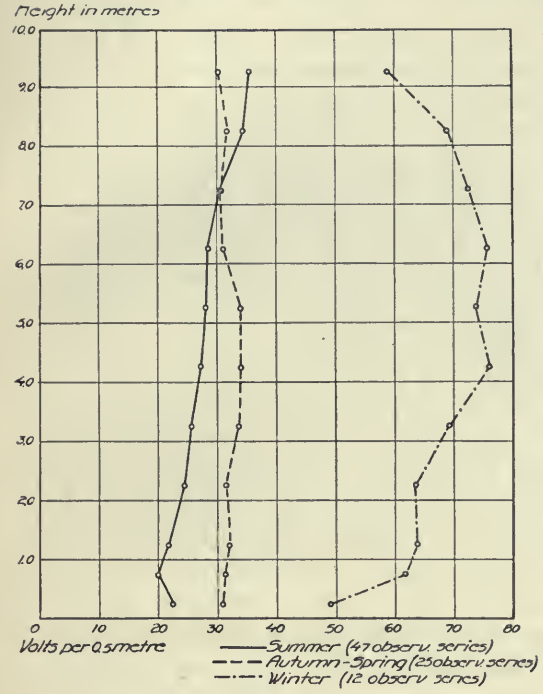

Fig. 22.

Fig. 23.

Average variation of potential gradient with height.

occurring in summer ought to be expected to cause a variation of the type obtained from the averages of this season. Autumn and spring ought in this respect to form a transition to the pronounced variation in winter, which no doubt often is the result of a great ion absorption in horizontally divided haze-layers.

Already during the observations with the stationary collectors a comparison between two groups that were equal with regard to the number of observations showed that lower wind velocities as a rule would cause higher values of dv_1, dv_2 and dv_3 as well as of the differences between them than the corresponding values in a group with higher wind velocity. If the same method is employed for all the observations of dv, with the modification that the registrations of the

anemometer on the roof of the adjacent Instrument Building of the Meteorological Institution [1] are used, the result given in table 24 is obtained. The observations of dv on Oct. 20th and 21st, Febr. 6th and 8th, and April 25th were omitted.

Tab. 24.

Wind velocity, m/sec.	Mean velocity.	Height in metres.									
		0.25	0.75	1.25	2.25	3.25	4.25	5.25	6.25	7.25	8.25	9.25
0.0—1.7	0.93	36.6 (30)	38.6 (36)	42.5 (36)	46.3 (36)	49.0 (36)	52.4 (36)	51.2 (36)	53.2 (36)	54.3 (35)	51.2 (33)	45.9 (29)
1.8—3.0	2.28	29.6 (26)	28.2 (38)	32.1 (38)	31.5 (38)	32.9 (38)	34.7 (38)	35.0 (38)	34.7 (38)	32.4 (37)	34.8 (35)	35.8 (32)
$\geqq$ 3.1	4.86	26.2 (37)	28.7 (45)	29.8 (45)	31.3 (45)	33.1 (45)	34.6 (45)	33.7 (45)	31.7 (45)	32.0 (45)	30.8 (42)	32.3 (40)

The observations have been divided into three different classes according to the average wind velocities during the times of observation. When the latter did not coincide with those of the anemometer, which recorded the average wind velocity for each hour counted from the half hour before the hourstroke, the values nearest in time to the observations of dv were taken in consideration. The table confirms the results obtained with the stationary collector system, though the tendency is still more pronounced. The potential gradients of the lowest wind velocity class are with regard to their absolute values considerably higher than those of the higher wind velocity classes. In addition to this there appears in the lowest wind velocity classes a much more pronounced variation with the height, while the average values of dv in the higher classes show only a small variation. In the lowest class the number of the winter observations is about 25 % of the total, while in the higher ones only 8 %, respectively 16 % of the whole number belong to winter. This will to some extent explain the different variation for different wind velocities, at the same time as it shows the connection between the variation with the height and the ion absorption in stagnated atmospheric layers in winter-time.

The data obtained by the observations of dv are not suitable for calculations of the variation of dv with the height during different hours of day and night, as the main part of the observations were made in the daytime. All the same it has been considered appropriate to make the following calculation from all the observations, where disturbed observations were excluded. The observations have been brought together into five different groups: Morning 8.0 a. m.—10.55 a. m. (21), midday 11.0 a. m.—1.55 p. m. (32), evening 2.0 p. m.—4.55 p. m. (24)

[1] Situated about 85 metres from the line of observations.

and 5.0 p. m.—7.55 p. m. (24), night from 8.0 p. m. and later (15). The number of observations in each group is given in parenthesis in the above classification, and the result is shown graphically in fig. 24.

The lowest average gradient as well as the smallest variation with the height is found in the midday observations, which also could be expected as the ventilation in the vertical direction is probably greatest at this time. The morning group and the first evening group show high averages and fairly pronounced variation with the height, and their tendency is analogous. For the lower heights the night observations show about the same absolute mean values of *dv* as the midday ones, as could be expected considering the daily variation in the lowest atmospheric layers, which had been observed with the stationary system. As a rule the evening maximum occurs as early as at 7 p. m., while at 8—10 p. m. the gradients had generally reached about as low values as at noon. In the night *dv* increases with the height right up to 6 m. contrary to the three curves further to the right in fig. 24.

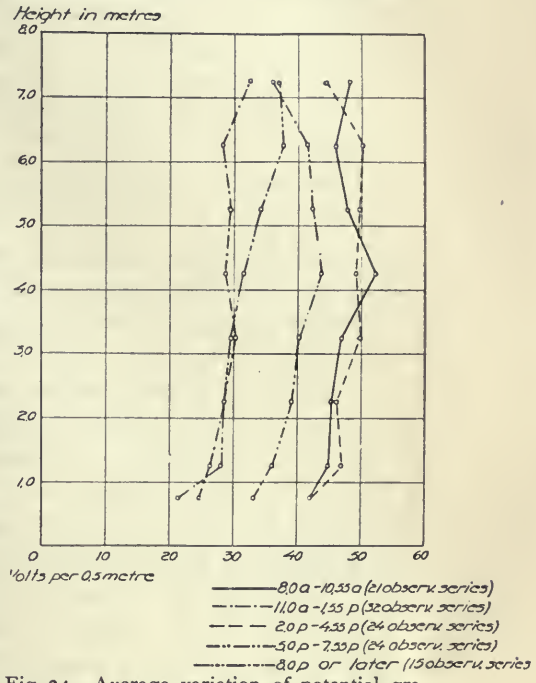

Fig. 24. Average variation of potential gradient with height as calculated for different hours of the day.

Connection between Variation of Potential Gradient with Height 0—9 metres and Visibility.

There must be a certain relation between the degree of visibility of the air and the potential gradient. At high percentage of dust and haze particles, a great absorption of ions will take place, which must cause an increase in the potential gradient. I have already pointed out more than once that horizontal layers of dust and haze will act as impenetrable sifts, which owing to the general current of ions are able to absorb light mobile ions to a great extent and change them into heavy ones and thus create great volume charges. The presence of such charges are often shown by great variations of *dv*. During a large part of the time from Oct. 4th 1919 to June 6th 1920 the visibility was often observed simultaneously with *dv* according to the following scale. (Tab. 25.)

The scale will be found in an earlier publication.[1] As points of observation

[1] International Meteorological Committee, Meteorological Office Publications, no. 237, p. 25, London 1919.

Tab. 25.

Visibility class.	Distance of most distant object visible, metres.	Visibility class.	Distance of most distant object visible, metres.
0	0— 200	5	4,000— 7,000
1	200— 500	6	7,000—12,000
2	500— 1,000	7	12,000—20,000
3	1,000— 2,000	8	>20,000
4	2,000— 4,000		

were used a number of objects located between NW and NNE, as for instance roofs, hills, telephone posts, and so on. An estimate of the visibility will of course be more or less subjective. The degrees of visibility are given after the dates of the respective values of *dv* in the table 22. We find for instance for Oct. 4th the figure 3. On account of the number of observations and the uncertainty of the individual values the dates are only divided into two groups: low visibility including values up to visibility = 5 and high visibility, values ≥ 6. The average of the first groups was 3.9 (29) and that of the latter 6.5 (26). The number of observations in each group is given in parenthesis. The observations on Febr. 6th and 8th and April 25th 1920 were omitted. The visibility of the air is related to the wind velocity and this was found also in the present observations. The average wind velocity for low visibility was 2.3 and for high visibility 3.0.

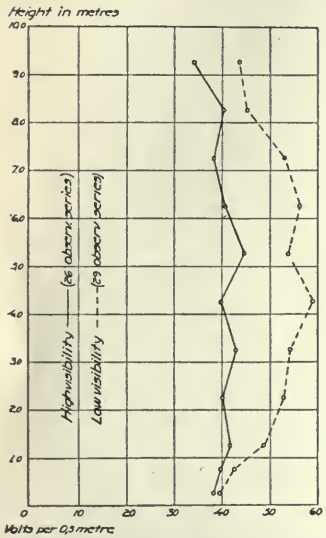

Fig. 25. Average variation of potential gradient with height as calculated for two different visibility groups.

Fig. 25 demonstrates the variations with the height for high and low visibility.

We find that the variation of *dv* for high visibility is considerably less pronounced than for low. This is especially the case if the values for different heights are evened out a little and the result fully confirms the importance of the rôle played by the absorption nuclei at the amassing of charges in the lowest layers of the air.

Some Remarks Concerning Individual Observation Series.

A comparison between the meteorological observations occurring in the Bulletins of the Meteorological Institution and the values of *dv* included in table 22 might be of some interest. In consideration of the small number of observations I limit myself to the following remarks on certain circumstances at the observations of the atmospheric electricity.

1919. In Sept. 28th and 29th the air was washed clean and the visibility was good. The great increase with the height at 6.25 m.—7.25 m. of *dv* on Sept. 29th 9.0—9.44 a. m. is not found in observation series made later on the same day. — Oct. 3rd. The air is comparatively hazy near the locality of observation, which also appears in an irregular variation at the greater height of *dv*. — On Oct. 11th 9.30—10.30 p. m. very clear air but in spite of that a very irregular variation with the height of *dv*. — On Oct. 20th 5.24—7 p. m. and Oct. 21st 8.30—9.30 a. m. the observations are probably to some extent influenced by stratus clouds at small height. On Oct. 24th 0.38—1.30 p. m. the air is hazy and there are comparatively low values of *dv* at certain heights. Soon before 3 p. m. the wind rises from NNE and drives away the hazy air, which is followed by increased gradients close to the ground in the observations 4.27—5.20 p. m. — Oct. 30th. The visibility for this day is observed earlier in the day; in the evening the layers close to the ground seemed to be filled with small condensation particles. The earth capillaries had also been choked with ice. High gradients were observed at 5.0—6.0 p. m., especially in the layers close to the ground. — Nov. 8th. Exceptionally clear and pure air after the snow-squalls that had passed the day before. On Nov. 11th as well there is very clear air. On Nov. 18th there is hard S wind, which is accompanied by very constant values of *dv*, especially close to the ground. — Dec. 27th. During the observations, an occurrence of condensation particles is noticed in hollows near the ground; very calm weather and probably a horizontal layering of the air. Very pronounced variation with the height of *dv*, while the potential at 2 metres is almost constant. — Jan. 22nd. Between 8.45 and 9.40 a. m. visibility 4; greatly varying values of *dv*, while at 3.0—3.50 p. m. the visibility is 7, and the variation of *dv* also less. — Febr. 6th 3.30—5.7 p. m. Very variable values of *dv*, while the visibility is comparatively good. Probably the strong wind carried air with a large amount of free charges. — On Febr. 8th in the morning there appeared stratus clouds, which dispersed at about 11 a. m. The values of *dv* vary very much at the observations 3.0—4.0 p. m. on the same day, which may be explained by remaining charges in the lowest atmospheric layers from the dispersed stratus clouds. V. Conrad[1] points out that when fog or haze disperses, the negative ions are first made free as they are light and mobile, while the positive ions remain longer, being heavy and mass-bound. The great variations of *dv* on Febr. 6th might possibly also be explained as caused by remaining charges from dispersed haze layers. On Febr. 13th in the morning a typical greyish brown haze-layer is observed in the neighbouring parts of the town, the greatest height of which was estimated to 15—20 metres above the ground. It was spread in a pronounced horizontal layering. Very great varia-

[1] Wiener Sitzber., *114*, 346. 1905.

tion with the height of *dv* was observed at 9.0—10.0 a. m. At 3 o'clock p. m. the haze-layers have dispersed, but all the same the observations of *dv* give very great variations with the height. — Febr. 15th. Very clear air, washed clean by the precipitation the day before. — On March 25th 10.0—11.0 a. m. variations of *dv* occur at the same time as a fairly hard SW wind. — On April 23rd 2.0—3.0 p. m. the sky was overcast and one had the impression that it might begin to rain any moment, which, however, did not happen. The values of *dv* were low. — April 25th. The air ought to be fairly pure after the rain that had fallen during the night. The weather was, however, hazy with visibility = 3, low nimbus clouds were passing rapidly. A very peculiar variation with the height was observed, suggesting a great separation of the ion charges in the lowest atmospheric layers. The variation of *dv* during this day has been considered so diverging from the normal one that the observations were omitted at the calculation of mean values. — April 28th. The air was washed clean but all the same fairly great variations of *dv* were observed.

SUMMARY.

The object of this investigation has been to determine the height variation of the potential gradient in the layers of air nearest to the ground. The locality of observation is a plane open field situated near the Meteorological Institution at Upsala. The spot to which all values refer is situated about 25 metres above mean sea level in lat. 59° 51.5′ N, long. 15° 10.5′ E from Greenwich. The arrangements of the experiments were as follows:

Two systems of vertical posts, 3.3 and 9.5 metres in height respectively, together with an instrument hut, were erected. Between the posts horizontal insulated steel wires were fixed carrying convenient collectors at the middle. By means of laboratory experiments in a homogeneous electrostatic field the charging qualities of different collectors were determined. For investigations either water spray collectors or polonium collectors of high activity were found to be useful; gas-flame collectors on the other hand gave uncertain potentials, and ionium collectors of the usual type and size gave too low potential values.

The electrostatic disturbance of the posts with regard to the middle points of the wires was estimated according to the calculations made by H. Benndorf. The disturbance caused by the instrument hut and the lower posts was determined by laboratory experiments. A model of the arrangements was introduced in a homogeneous electrostatic field between two sufficiently large condenser-plates. On probing the potential gradient at points corresponding to the middle points of the wires by means of a water-spray collector the disturbance was found to amount to 2 per cent, the percentage decreasing upwards.

At the beginning of the observations an arrangement of water-spray collectors, constructed by the author, was used. Thin brass tubes were suspended along the insulated wires, at the middle of which the tubes carried appropriate jet mouth-pieces. The water-spray collectors were exchanged, especially to suit winter conditions, for polonium collectors. The potential differences of the collectors were observed by means of self-recording electrographs of the Benndorf pattern.

Observations of the height variation of the potential gradient were undertaken both by means of a stationary collector system, where the collectors were placed at a height of 1, 2 and 3 metres respectively above the ground, and by means of a movable system with a distance of 43 cm. between the collectors. In the stationary system observations were undertaken during 330 days (1st August 1918—31st July 1919). The potential gradient was studied during 1095 observation hours unaffected by accidental meteorological disturbances such as precipitation, fog etc. and during 591 hours slightly affected by such phenomena. For each observation hour a mean value of the potential gradient was calculated during 11 consecutive minutes at each of the three collector points. In the movable system potential differences were observed (during 3 minutes), as a rule at 11 height intervals from the ground to a height of 9.5 metres above it. Observations were undertaken generally under undisturbed conditions, in 125 observation series from August 21st 1919 to August 13th 1920. The observations of the two systems are given in separate tables.

The gradient values have been submitted to discussion in connection with meteorological elements.

Absolute mean annual and seasonal values are given in table 26 (1095 observ. hours) and fig. 26. The values are corrected for the small disturbance of the hut and the posts.

The curves represent: No. I mean summer values, II mean winter values, III mean spring—autumn values, IV a curve showing the probable height variation calculated by M. Behacker.

Tab. 26.

Observation intervals above ground.	Potential gradient at Upsala. Mean absolute values in volts per metre.			
	Summer. (340)	Spring and Autumn. (340)	Winter. (415)	Year. (1095)
0—1 metre	35.1	49.2	80.0	55.8
1—2 metres	36.4	49.1	84.4	57.6
2—3 metres	40.9	57.7	95.4	65.5

The mean values of the gradients in the table show throughout lower values than the corresponding mean values of the curves in the figure. This is quite clear from the fact that the mean values of the table contain observations made at night, while the curves have been obtained mainly by means of observations in the daytime. Considering that the observations were carried out during two different years and the varying numbers of these observations it must be admitted that the results from the fixed and the movable systems show good aggreement.

According to the author's investigation the potential gradient at Upsala is considerably lower than the potential gradient that has been found to be the mean value for Europe. The author has shown the same thing in an earlier

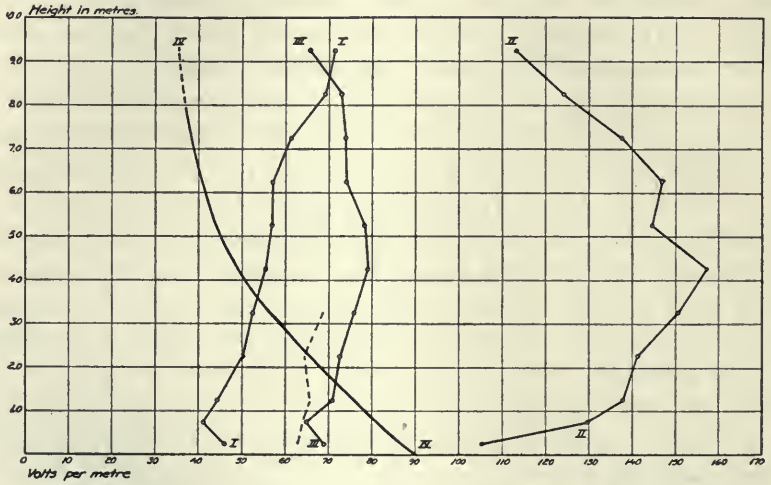

Fig. 26. Average variation of potential gradient with height at Upsala.

investigation, carried out according to the method that has hitherto been almost the only one used in determining the potential gradient. According to curve I in the figure, the height variation of the potential gradient shows a decrease nearest the ground, indicating a positive charge for this layer during summer. The observations thus seem to support Ebert and Kurz's investigations, which gave as their results an outflow of positive ions in excess through open capillaries from the earth. If the vertical upstream of warmed air is not sufficiently strong the external positive field can prevent the ions from coming from the layers nearest to the earth. The fact that the ions remain there must obviously cause a marked decrease of the potential gradient. As is seen from curve I the sign of the charge changes even at the third interval. The potential gradient increases up to a height of 5 metres, is almost constant at 6 metres, and then increases again..

Curve III (autumn and spring) shows a change of sign in the charge nearest

to the ground that is probably due to too few observations in the lowest height interval in comparision with the higher ones By constructing a curve (the not firm line in the figure near curve III) for the season with an equal number of observations in the lowest height intervals, the curve gets a straighter course. Thus it gets an intermediate shape between curves I and II, which was to be expected, as the out-flow from the earth capillaries ought to be less in autumn and spring than in summer. The potential gradient increases from the height of 0.75 to 4 metres.

In curve II (winter), on the other hand, there is no decrease in the potential gradient in the second interval. This might be expected at this season, when the capillaries of the earth are frozen and the ground is covered with snow. The winter curve is less regular than the ones for autumn—spring and summer, which is probably partly due to the smaller number of observations. During winter

Tab. 27.

Volume charge in electrostatic units per cubic metre. Upsala.												
Height intervals. Metres above ground	Fixed coll. system.		Movable collector system.									
	0—2	1—3	0.25—0.75	0.75—1.25	1.25—2.25	2.25—3.25	3.25—4.25	4.25—5.25	5.25—6.25	6.25—7.25	7.25—8.25	8.25—9.25
Summer	—0.03	—0.11	+0.25	—0.17	—0.15	—0.06	—0.07	—0.03	±0.00	—0.11	—0.20	—0.05
Winter	—0.11	—0.29	—1.29	—0.43	—0.08	—0.24	—0.17	+0.33	—0.05	+0.24	+0.35	+0.29
Spring-autumn	±0.00	—0.22	(+0.21)	(—0.31)	—0.04	—0.08	—0.08	+0.02	+0.11	±0.00	+0.02	+0.19
Year	—0.05	—0.20	(—0.07)	(—0.28)	—0.09	—0.10	—0.18	+0.13	+0.02	+0.02	+0.01	+0.07

the lowest layers show a marked negative charge. The sign of the charge changes at a height of 5—6 metres and is positive higher up. The observations support the view that ion-absorbing layers are of great importance for the height variation of the gradient in winter. The change of sign in the charge, which in winter and autumn and spring appears at about the middle of the interval used, is in the summer probably situated above the region of observation. The reason for this is possibly that in summer there is a stronger vertical ventilation in the lowest layers of the air.

It is perhaps convenient by means of Poisson's equation to try to calculate approximately the resulting volume charge by using the mean observational values of potential gradient. It may be considered that the values for the fixed system are certain within 0.2 volt per metre and for the movable system within 0.5 volt per metre. The volume charge is expressed in electrostatic units per cubic metre and the values obtained are given in the table 27.

As will be seen from the table, the charge is subject to very marked variations. This is due to certain accidental circumstances connected with the complicated nature of the meteorological phenomena. The chief interest of the charge values lies in their order of magnitude and in the indication they afford us as to the limits of variation during the different periods of observation.

The main result of the author's investigation is that the potential gradient is subject to a very marked variation in height, whose course is quite different from that which has formerly been considered to predominate in the lowest atmospheric layers. The chief reason for this is that heavy ions are of very great importance for the constitution of the electric field of the atmosphere. In the lowest layers of the air apart from the stratum nearest the ground there prevails as a rule a negative charge in excess, probably consisting chiefly of heavy negative ions.

The present investigation was carried out at the Meteorological Institution of the University of Upsala. It is a continuation of an earlier investigation on the potential gradient made by the author. The impulse to this work came from Professor F. Åkerblom, the Prefect of the Institution. He kindly placed the collection of instruments belonging to the Institution at my disposal. During the course of the work he gave me much valuable advice and information, for all of which I take this opportunity to express my very best thanks. I am also especially indebted to the Royal Swedish Board of Waterfalls, who allowed me to use for this work an external apparatus intended for investigations of the electric field during thunderstorms.

Through the good offices of Professors Svante Arrhenius and G. Granqvist three quadrant electrometers were placed at the disposal of the Institution for the purpose of this investigation.

The Municipal Electrical Works through their Superintendent Orvar Sturzen-Becker kindly allowed me to use a large accumulator battery. I was given permission to carry out certain laboratory investigations in the large machinery hall of this works. For these privileges and for other help I wish to express my gratitude.